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Non-Preferred Limb Performance Following Prolonged Training periods: Performance and Retention of Skills

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Non-Preferred Limb Performance Following Prolonged Training Periods: Performance and Retention of Skills

By

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Abstract

The purpose of the current study was to examine if a long-term training program could improve non-preferred limb performance on a battery of standard tasks (Annett Pegboard, Grooved Pegboard Place and Remove Phase) and non-standard tasks (Scroll Task and Line-crossing Task). Upon completion of the training sessions, two new tasks were introduced, Finger Tapping and Fitt's Law Task, to examine if any performance improvements could be transferred. A second purpose of the study was to learn if a training program could increase the perceived comfort in using the non-preferred hand on the same testing tasks. Participants were assigned to a 1-week training group (3 sessions over 7 days, N = 21), 3-week training group (9 sessions over 21 days, N = 15) or no training control group (N = 20). Training sessions were derived based on the suggestions of the Ackland and Hendrie (2005) study and consisted of 20-30 minute sessions with a focus of non-preferred limb training on multiple tasks. Post-training testing found that though the non-preferred hand never does reach an on par performance with the preferred hand at the same point in time, the Grooved Pegboard Place phase and Scroll tasks, both had significant improvements in non-preferred hand performance over the course of the study. The training was task dependent, as no transfer of training was found on the two transfer tasks. Perceived comfort also improves with repeated exposure to a task, though training and hand improvements were not determining factors, as there were no group differences between tests. The results suggested that a training period of 2- to 3-weeks was all that was required to see improvements in the non-preferred hand, but the learning does appear to be task specific.

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Non-Preferred Limb Preference Following Prolonged Training

Repetitive practice where the task is performed using the same movement pattern can lead to overuse injuries. A typical computer setup situates a computer mouse on the right side of a keyboard to accommodate the nearly 90% of the worlds right hand population (Annett, 1985). The setup encourages people to use the computer mouse with only one hand, which can lead to nerve conduction problems or problems such as carpal tunnel syndrome (Muggleton, Allen & Chappell, 1999). One solution to limiting wrist injuries from overuse could be switching hands when performing repetitive manual tasks. Yet despite this seemingly simple solution, very little research has examined the effects of prolonged practice on the non-preferred hand and its ability to retain such training. The current study consisted of two experiments. The first experiment established a training protocol by examining if there were differences in measures of hand performance. The second study was used to determine if a training protocol could be used to increase performance and comfort of the non-preferred upper limb for multiple motor tasks, and more specifically, computer use. Secondly, the study examined how much, if any, retention occurs in fine motor tasks that were practiced over long periods in the non-preferred limb. Finally, the study attempted to examine whether a training program of fine motor skills could be carried over to new activities requiring high degrees of skill.

What is Handedness?

At an early age we are honed to perform tasks in a way which will allow for efficient completion of a task. Despite there being many different ways to perform a task, the simplest way to complete a job is selected more often than not (Rosenbaum et al, 1993). Regardless of the activity, simple or complex, there is generally one hand that is more comfortable and efficient at completing a task. The feeling of comfort, ease and preference in using one hand over the other is functional human lateralization.

Laterality is a form of specialization or greater development of one aspect of an otherwise symmetrical entity. For instance, lateralization can be a structural difference, such as the asymmetrical language areas in the brain between hemispheres, or functional, such as an ear dominance for listening. Functional lateralization is seen in humans with handedness, where approximately 90% of the world is markedly right-handed, while the remaining 10% is considered left handed or ambidextrous (Coren, 1990; Annett, 1985; Coren & Porac, 1977). The incidence of handedness is also relatively constant across the world, though it has been reported that the Western countries have higher rates of right handedness, as well as males having slightly higher incidence of left handedness than the female counterpart (Harris, 1990; Medland et al, 2004).

Handedness can be measured as the hand one performs most efficiently and accurately with, hand performance, or the hand in which a person prefers to use regardless of efficiency and accuracy, hand preference.

Hand preference is the hand an individual will use when performing any unimanual task such as writing or throwing. The preferred hand will usually be more proficient at completing these tasks, though not always, and likely feel more comfortable for the performer as well. The simplest way to assess someone's hand preference is to ask which hand the person uses to write with, though more quantitative methods are typically used. The Annett Handedness Questionnaire (Annett, 1970) and the Edinburgh Handedness Inventory (Oldfield, 1971) were developed to evaluate how individuals prefer to use their hand when performing a variety of simple and complex tasks on a variety of small to large objects. Individuals answering the questionnaires respond by marking preferences labelled "always", "usually" or "equally". In general, a numerical value is assigned to each response before administered to a participant, which upon completion is totalled to obtain a preference score. In doing so, researchers can than classify groups of individuals based on consistent- or inconsistent hand use. By assigning numerical values a more detailed analysis of hand preference across tasks and between studies can be done.

In general, research has found that right-handed participants tend to be very consistent in reported hand use, often citing little to no left hand use, and second, left-handed participants tend to be less lateralized, in that they will use the non-preferred hand on greater occasion than the right-handed counterpart (Steenhuis & Bryden, 1989).

In contrast, performance measures of handedness eliminate the subjective recall of preference measures and classify individuals into categories of handedness based on the performance difference between the hands during a task. Examples of performance measures include finger tapping (Peters, 1981) and the Annett Pegboard (Annett, 1976), which quantify the hand performance differences based on the number of taps recorded over a timed period and the time required to move a set of pegs over a distance on a pegboard. The final step of most performance measures includes calculating a laterality quotient (Nalcacy et al, 2001; Bryden, Pryde & Roy, 2000). A laterality quotient is a calculated ratio comparing right- and left-hand performance as a function of overall performance, which can then be used as a comparative tool to other known asymmetries such as language dominance (Natsopoulos et al, 2002; Corbetta, Williams & Snapps-Childs, 2006).

The benefit of using the performance measures of handedness is that nearly any task, simple or complex, can be used in some way to assess handedness. Regardless of the task complexity, it has been argued that novel tasks are a fairer assessment of hand performance than practiced ones (Peters, 1998). Common motor performance tasks include the Grooved Pegboard Test (Lafayette Instruments #32025), which assesses the manipulative ability and motor speed of the hands by moving small oriented pegs to matched slots and the Annett pegboard which examines motor speed and control when moving large pegs from slots far from the body to a closer destination. Finger tapping and grip strength are simpler tasks, where individuals tap a finger for a predetermined time or squeeze a hand dynamometer. Yet regardless of the task chosen, research has shown that different tasks will result in different manual asymmetries scores (Brown et al, 2006; Brown et al, 2004).

In general, most of the performance measures show that the preferred hand performs at a faster and more accurate rate than the non-preferred hand (Bryden, Pryde & Roy, 2000; Peters, 1998; 1980). The advantage is likely due to a life time of practice and frequent preferred hand use leading to greater control when using additional sensory information in the preferred hand. Yet, some tasks are susceptible to showing an advantage of speed, accuracy or both in the non-preferred (Corey, Hurley & Foundas, 2001). More specifically, finger tapping and the Annett pegboard have been shown to have no preferred-hand advantage on repeated occasions (Corey, Hurley & Foundas, 2001: Bryden, Roy & Bryden, 1998).

Performance measures of handedness are not perfect. It is difficult to know in performance measures to what extent the task utilizes sensory information. More specifically, if an individual is a poor performer on the Grooved Pegboard, it cannot be clearly stated if the problem is a manual dexterity issue or visual problem without additional testing. Generally, when using performance measures of handedness tasks will use speed, through reaction and movement time, as the dependent variable (Bryden & Roy, 2005; Brown et al, 2004; Lavrysen et al, 2003; Lee & Magill, 1983). Motor speed should not be the only measure taken, considering many daily tasks require precision and coordination, other variables must be gathered in order to accurately describe the performance differences between two hands. Yet more often than not, these variables are excluded because they make tasks far more difficult and time consuming to perform.

Another concern of performance measures is that there is an abundance of tasks to choose from, each with the potential measure different components of handedness. This can limit the ability to generalize results across studies and relate tasks together. For example, dot marking tasks correlate well with hand writing and drawing tasks, a fine motor skill, and peg moving often relates to hammering, a gross motor skill (Corey, Hurley & Foundas, 2001; Steenhuis & Bryden, 1999). However, in general, it is the preferred hand that is often the better hand at performing most manual tasks.

Effects of Long-Term Practice on the Preferred Hand Advantage

For the better part of the last century researchers have examined, in detail, many aspects of practice and the advantages for learning fine motor and gross motor skills, as well as new and experienced tasks (Memmert, 2006; Lee & Magill, 1983; Kleinman, 1980; Fleishman & Parker, 1962; Provins, 1958). However, very few studies have examined the long-term effects of practice on the performance of the non-preferred hand and only one known study attempted to determine the comfort an individual has in performing them (Ackland & Hendrie, 2005). More importantly, only a few studies, which will be detailed in later sections, have examined practice on the non-preferred limb over a long period of time in an attempt to compare performance between hands (Ackland & Hendrie, 2005; Heath & Roy, 2000; Peters & Ivanoff, 1999). There is a need to further research the topic non-preferred limb training in an attempt to help ease the burden on the preferred limb. Whether the workers sit at a desk or are manual labourers overuse injuries are avoidable and costly (Hou, Hsu, Lin & Liang, 2007; Bonfigliol, Mattioli, Spagnolo & Violante, 2006; Andersen et al, 2003).

Recent research has looked at extended practice to determine if there are immediate training benefits for hand performance. Schulze, Luder, and Jancke (2002) examined the effects of a four-week training session on the performance of moving a peg across a pegboard. In an attempt to learn about bimanual transfer, the participants were grouped according to the hand that they would train. The non-preferred or preferred hand was either trained separately or together. For each session, trials were randomized based on the difficulty of the task performed. The training consisted of practicing different variations of the testing tasks with both hands where participants moved a pegs from one side of the board to another. Variations were performed by changing the distance between the sets of holes to increase the movement needed to complete the task. A significant training effect on both hands regardless of the training group was found. However, intermanual transfer, when training in one hand results in the improvement in the other non-trained hand, was weakest when training the preferred hand only. An aspect the researchers failed to expand upon was the comparative level between the preferred and non-preferred hand performance following training, as well as comparing the effect of training the non-preferred hand to that of the control with no training at all. Lavrysen et al (2003) performed a similar study using a manual aiming task with emphasis on movement and reaction time measures. Following a training period, tests on a manual aiming task showed that both preferred and non-preferred hands were capable of learning tasks from direct or through asymmetric training. Of interest, the Lavrysen study group noted that the right-handed participants had greater control over the non-preferred hand than did the left-handed participants. The control of the non-preferred limb indicated that for right-handed individuals the lack of non-preferred hand use may be largely psychological. Findings based on the error measures during the aiming task suggested that these participants were capable of performing at a high level with the non-preferred hand.

Provins (1958) examined whether pressure replication and speed oscillation differed between the preferred- and non-preferred hands after a training period. Following four weeks of practice with the testing tasks, the study concluded that when allowed visual feedback the non-preferred hand could perform as well as the preferred hand, whether they were right- or left-handed, in pressure reproduction, but lacked the ability to oscillate at the same high and consistent speed. Provins (1958) summarized that the non-preferred hand was capable of performing at near-to or equal levels as the preferred hand.

A later study countered Provins conclusions. Here, Peters (1981), in a study of finger tapping, found that following a period of training, the non-preferred hand never approached a level of performance close to the preferred hand, yet both improved significantly following practice. Peters (1981) identified only individuals of strong right-handed nature, unlike Provins (1958) who used both left- and right-handed individuals and trained both hands. Both studies would have benefited from performing a follow-up that could relate these tasks to one that is reflected in an industrial job. A more ecologically valid task, such as computer tasks or tool manipulations, would increase the external validity of each of these studies and provide a necessary application.

More recently, Heath and Roy (2000) evaluated the results of an intense training program on the non-preferred limb of an individual with extensive knowledge of a tracking and reaction time task with the preferred hand. In this case, a right-handed individual trained their left hand on a tracking task using a computer mouse for 5600 trials. The study examined the practice effect on the kinematics of the limb movement, and included measures such as movement time, peak velocity, time to peak velocity and spatial position of the cursor. As expected, the earliest sessions showed a clear superior performance of the preferred hand as compared to the non-preferred hand. However, towards the middle and end of the training period the non-preferred hand performed at a movement time equivalent of that to the preferred hand. When examining the other kinematic data the results were similar; later training sessions showed marked improvement in the non-preferred hand measures of kinematics. Of note was that the non-preferred hand deceleration phase actually improved to a point that was nearly on par with the preferred hand despite the longer time required to reach peak velocity and less accurate initial impulses.

Health and Roy (2000) concluded that though the non-preferred hand never did reach an on-par level of performance with the preferred hand, a significant functional improvement occurred and that there was possible evidence that the non-preferred hand became more proficient in the use of online-response feedback. This suggests that the non-preferred hand was becoming better suited to adapt to initial movement impulses in a manner similar to the preferred hand, a behaviour not seen before in a research study. Though the preferred hand continued to show lateralized performance benefits, Heath and Roy were the first to show that extensive long-term practice can show tremendous behavioural adaptation in the non-preferred hand.

Peters and Ivanoff (1999) studied a relatively novel, but well-practiced task of mousing on a computer for left-handed computer users. Since most computer mice are designed to be used by a right-handed individual and positioned on the right side of the computer, left-handed individuals who sought out left-handed mice were considered a minority. Peters and Ivanoff (1999) gathered three different groups of individuals: left-handed, left-handed mouse users (LHLM), left-handed, right-handed mouse users (LHRM), and right-handed, right-handed mouse users (RHRM) and studied their kinematic data for both hands through a series of computer tasks. The first task tested the speed and precision by measuring the participant's ability to react to an onscreen signal, in this case a dot, and mark it with a cursor. The second task was a precision task in that the participants performed a movement, which bisected a line that appeared on screen with the mouse cursor onscreen. In both the first and second tasks, an unknown third measure of linear deviation was quantified using an imagery line. A perfect movement plot, as determined by the researchers, was superimposed on the actual movement and the deviation from that line was taken as movement control.

Since the task was believed to be well-practiced, no training protocol was deemed necessary, however each participant was allowed 20 minutes of practice to familiarize themselves with the tasks. The reaction time results showed that both the LHRM and RHRM had a right-hand advantage for performing the task but the LHLM group did not show a significant difference between the hands. The targeting portion of the first task showed similar right-hand performance superiority for both RM groups and an advantage for the left hand for the LHLM group. Though the between-hand difference was significant for both reaction time and targeting, Peters and Ivanoff (1999) reported that the actual difference between the two hands was approximately 0.3 s and suggested that the effects of practice were not as strongly pronounced as previously expected.

For the precision task, there was a marginally significant advantage of the right hand for both LHRM and RHRM groups, but no such advantage was found for the LHLM group. The line deviations also showed a similar slight superiority of the preferred mousing hand for both LHRM and RHRM groups and no advantage for the LHLM group, however further analysis led to a conclusion that the overall magnitude of the effect was marginal and virtually unnoticeable if viewed by eyesight only. In conclusion, Peters and Ivanoff (1999) believed that using the non-preferred hand could be a viable substitute to ease the burden of a single hand performing all the mousing duties, thus preventing some avoidable overuse injuries.

Though Peters and Ivanoff (1999) provided insight into the effects of long-term practice on the non-preferred hand, the study still failed to examine how practice affected an individual's comfort or perception of using the non-preferred hand as a matter of preference. Ackland and Hendrie (2005) examined hand preference for a battery of mousing tasks from an ergonomic point of view while examining performance improvements in the non-preferred hand. Ackland and Hendrie (2005) sought a group of experienced computer users who routinely used only the right hand to perform mousing activities and were thus at risk of developing such injuries. The study was the first to use both an experimental group, which performed training with the non-preferred hand, and a control group, which performed the same regiment of training but with the preferred hand only. It was also the first study that not only quantified hand performance for both hands for multiple computer tests but also measured the perceived comfort of hand use on a daily use per session. The training session spanned 3 weeks with 30 minutes of training for 5 days of the week and included six tasks, three that were actually used in the testing.

The testing tasks included a Scroll Task, which tested the general computer use on a word processing document and required individuals to performs sets of instructions within a word document; a Line-crossing Task, which tested upper limb accuracy and motor control by having participants connect sets of parallel lines with a perpendicular line created using the mouse; and a Fly Task, which involved tracking a fly on screen and "swatting" it with a fly swatter on screen using the mouse as a method of control. Each task was related to activities of daily-living, which increased the external validity, unlike previous studies. Ackland and Hendrie (2005) demonstrated that the control and experimental group were comparable at pre-training trials and therefore, could contribute any performance changes to the training program implemented.

The training protocol consisted of variations of the actual testing tasks, as well as some novel tasks that were carried out only during the training period. All the tasks were performed on the computer by the use of a mouse. In a single 30-minute session, participants would complete the following: button-sequence task, requiring the activation of specific on-screen icons by clicking with a mouse; computer minesweeper and solitaire, which involved playing the game using the mouse to uncover "bombs" and organizing cards, and varied versions of the fly task, scroll task and lines task. Each session consisted of 10 minutes of preferred-hand training and 20 minutes of non-preferred hand training.

Ackland and Hendrie (2005) concluded that when performing the visual tracking task (Fly Task), the non-preferred hand of the participants neared an on par performance with the pre-trial testing of the preferred hand, which could not be said of the control group. Similarly, the line connection task revealed marked improvement of the non-preferred hand in only the experimental group, however this task, did not seem to hold the same on par performance as the pre-trial preferred hand. The final scroll task, which reflected that of a business setting, was the most successful in terms of performance enhancement. The experimental group performed this task at a level that exceeded that of the preferred hand on the pre-training testing upon completion of the training program. Thus, upon completion, significant changes in all three tasks were found. More importantly, all the results were attributed to the 30 minute training program, which demonstrated that the non-preferred hand could on par with the preferred hand.

The strength of Ackland and Hendrie's study was its novelty. They examined how the hands performed tasks reflecting daily activities. The novelty of the tasks may also be a weakness as it makes comparisons to previous findings difficult. It was unclear whether the participants were strong or inconsistent right-handed individuals since the study lacked a performance measure. The fact that the non-preferred hand of participants was trained so quickly, it could be argued that the group was not representative all right-handed individuals. A second control group, who were not computer graphic designers, would help counter this argument. A strength of the study was that training was relatively simple at only 30 minutes per session and carried out five days during the working week over the course of three weeks. This means that it would be easily implemented into a typical work schedule with very little disruptions.

Rationale for the Proposed Experiment

There is one major underlying flaw to each of the long-term practice studies examined. None of the studies has ever examined the retention of the newly acquired performance skills of any of the tasks. Though Heath and Roy (2000), Peters and Ivanoff (1999), and Ackland and Hendrie (2005), provided excellent examples of performance improvements following a training program, none included a retention period. Therefore, it is unclear whether such performance improvements are temporary effects or permanent. The length of the training period also seems to go unexamined, in that both Heath and Roy (2000) and Ackland and Hendrie (2005) evaluated training periods that span the course of approximately one month. Though the cost associated with performing tasks of such length is high, to establish the minimal time required to obtain training effects could optimize training. Finally, as mentioned earlier all of the studies neglected to compare how standard performance tasks, such as pegboards, perform versus the non-standard performance tasks, such as scroll tasks on a computer.

A second reason to complete a study of prolonged practice on the non-preferred limb is due to the overuse injuries associated with repeated bouts of the same activity every day. One such injury is carpal tunnel syndrome (CTS), which has been reported as an avoidable workplace injury that is extremely costly to work place productivity loss each year (Hou et al, 2007). CTS is a musculoskeletal disorder which can be caused by factors including forceful, repetitive and high vibrations movements, which when combined can have an additive effect (Bonfigliolo et al. 2006). As such, many manual labourers including construction and factory workers have been noted to be at a higher risk of suffering from the disorder than the non-manual labourers (Bonfigliolo et al. 2006). Additionally, improper use of the mouse and keyboard through repetitive wrist movements and arm movements are thought to be a possible cause of medial nerve conduction problems and CTS in workers who spend a large portion of the day in front of a computer (Andersen et al, 2003; Anton et al. 2001). The most interesting finding from these studies is that in nearly all the cases of the CTS or medial nerve conduction problems, the non-preferred hand is never diagnosed with the injury on its own. In all the cases, the majority of the people are affected to the preferred limb only or in cases of bimanual symptoms, the preferred limb is marked with having considerably worst discomfort. Such asymmetrical damage is likely because the preferred limb was overused by these individuals, yet it is currently unknown whether this this can be avoided by practice with the non-preferred limb.

The purpose of the current study was to examine the effects of prolonged practice on the non-preferred limb of right-handed individuals on a battery of standard, tasks used in previous studies with standardized scores, (Grooved Pegboard Remove and Place Phases, Annett pegboard) and non-standard tasks, tasks that do not have standardarized scores from previous studies, on a computer (Line-Crossing, Scroll Task) in terms of both performance and comfort. Secondly, the study will examine if any performance improvements can be transferred to new tasks (Finger Tapping, Fitts' Law Task) following the training period. The study will try to replicate the results of Ackland and

Hendrie (2005) and add a new measure of perceived control and comfort in the non-preferred hand in completing the task.

Two experiments were conducted for the current study. The first was used to determine how each of the selected tasks measure the performance differences between the hands and the overall time required performing each task. Upon completion of the first experiment, the data was used to create a training protocol to be used in a second study. The second study was used to answer the main study objectives of how training affected non-preferred limb performance and comfort.

Experiment One: Task Comparison for Handedness Measures

A current limitation of standardized hand performance measures is the lack of tasks that represent activities of daily life. Pegboards have been shown to be excellent tools to build upon theoretical foundations of handedness (Bryden & Roy, 2006; Bryden, Bulman-Flemming, & MacDonald, 1996), however performance studies do not attempt to relate pegboard tasks to more practical tasks such as tying a shoe or using a computer. In doing so, a direct link between the theoretical work and practical training could be used to help develop meaningful protocols for rehabilitation or practice to avoid overuse injuries without the need for expensive equipment.

The current study examined two standard performance tasks (the Grooved Pegboard Test (both place and remove phases) and the Annett Pegboard) and two non-standard tasks performed on computer (the scroll and line-crossing task). One goal of the current study was to determine if these tasks differ in the assessment of handedness, by examining laterality quotients, and then to determine if any of the tasks correlated with each other. A laterality quotient is the calculated difference in hand performance as a function of the total performance. This was done so individuals who were relatively fast performers of a task can be compared to individuals who were relatively slow at performing the same tasks. In the current study, all laterality quotients were calculated ratios of hand performance where positive numbers indicated a preferred hand advantage and negative numbers indicated a non-preferred hand advantage.

Since computers have become a part of daily life and the computer mouse focuses primarily on single hand use, it would be an excellent comparative tool for performance studies of handedness. A second purpose for examining the experiment tasks was to determine which would be used during a training protocol in an attempt to train the non-preferred hand on a selection of standard pegboard tasks and non-standard computers tasks in a future study. The tasks would be chosen based on how each measured hand performance difference in an attempt to eliminate redundant measures, examined using correlations, in order to maintain a training session of approximately 25-30 minutes. The training protocol would be used in a second study which examined the affects of training on the non-preferred hand on a series of standard and non-standard tasks.

Method

Participants

A total of 18 right-handed participants (10 males and 8 females) performed the study and were all right-handed according to the Waterloo Handedness Questionnaire. Each participant owned and regularly used a computer and computer mouse. Participants were given monetary compensation upon completion of the study.

Procedure and Materials

Hand preference assessment was done using the Waterloo Handedness Questionnaire (WHQ). The WHQ consisted of 32 items regarding preferred hand use for skilled and unskilled tasks. Each question was answered on a 5-point scale ranging from (-2) always left, (-1) usually left, (0) equal use, (1) usually right and (2) always right. Participants were instructed that activities that have single hand use of 95% or more are considered "always", between 75-95% are considered "usually" and less than 75% is considered equal use. The questionnaire was then used to create a sum total to ensure that the individual was right-handed (individuals with a positive sum score were considered to be right-handed).

Each participant began the study by performing the Waterloo Handedness Questionnaire (WHQ) followed by a set of tasks. Each task was presented in the same order but counter-balanced for the hand to which they started. The tasks were as follows: <u>Grooved Pegboard Test</u> The Grooved Pegboard Test (Lafayette Instrument #32025) was included in the current study because of extensive use in previous studies as a performance measure of handedness and was used to compare hand performance with the non-standard tasks. The Grooved Pegboard Test assessed fine motor skill with emphasis on speed and manipulative ability of the hand and fingers. The Grooved Pegboard also required a high degree of visual-motor coordination. The board is 27.6 cm by 10.6 cm and consisted of a peg slot area in the upper half (10.1 cm by 10.1 cm) and a circular receptacle in the bottom half (8.7 cm in diameter) that contained 25 oriented pegs (2.8 cm long). The task was timed and began when the first peg was inserted into the upper most contralateral slot and filled in a contralateral to ipsilateral manner from top to bottom, stopping when the last peg was inserted into the board. Each peg was picked up from the receptacle at the bottom of the board and then placed into a slot, which was 0.5 cm in length and separated by 1.7 cm between holes, using only one hand at a time. Upon filling the peg slots the participants were then timed for taking the pegs out in the same order they were inserted. Both the non-preferred and preferred hand performed the task three times for both the remove and place phases. For logistical reasons the place phase always preceded the remove phase of the task and individuals were counterbalanced for the starting hand. The dependent measure for the Grooved Pegboard was the time to complete the task in seconds. A laterality quotient was then calculated from the movement times {(NP-P/NP+P)*100}.

<u>Annett Pegboard</u> The Annett Pegboard was included in the current study as it provided a standardized task that had been used in previous studies and was used to compare hand performance with the non-standard tasks. The Annett Pegboard assessed motor speed and accuracy with an emphasis on speed control and targeting ability. The Annett Pegboard consisted of 10 dowel-shaped pegs located distal to the body in peg slots and had to be moved as quickly as possible to matching holes located directly across the board in a contralateral to ipsilateral fashion. The pegboard was a rectangular board 30 cm by 18cm with a separation between hole sets of 15 cm. Each peg is 7 cm long and 1.1 cm in diameter and placed in peg slots 1.2 cm in diameter. The pegs were moved one at a time, as quickly as possible by the participant while seated at a comfortable distance from the board. The task was a timed event, which began when the first peg was placed into the matching peg hole and ended when the last peg had been inserted into the slot. Each hand performed the task three times and the times to completion were used to calculate laterality quotients {(NP-P/NP+P)*100}}.

Line-Crossing Task The purpose of using the line-crossing task was to attempt to replicate the results of Ackland and Hendrie (2005). The task was included to help individuals learn how to coordinate mouse movements to perform a goal that requires accuracy and speed. The line-crossing task assessed the ability to accurately manipulate a computer mouse to complete a series of tasks meant to mimic that of a simple graphics design or manual graphing function. The task required participants to use Microsoft Paintbrush to create a connecting perpendicular line between two parallel lines on a screen resolution set to 1024 x 768. The two parallel lines were 6.35 cm in length and required a 2.54 cm connecting line between them. The first four lines were connected using a top-bottom connection and the second four required a left-right connection between the parallel lines. The pattern of four top-bottom and four left-right connections was repeated twice for a total of 16 possible connections. The dependent measure was the time to complete the task and was completed with both hands three times each. In order to be considered a valid connection the lines were to be unbroken and completely straight between the two lines. Please see Appendix A for pictures of proper and improper completion of the task.

Scroll Task The scroll task was included in the current study in order to replicate previous findings by Ackland and Hendrie (2005) using a similar task and procedure. The task helped individuals learn how to coordinate mouse movements to manipulate computer documents so that the presentation would match specific requirements.

The scroll task required knowledge of a computer and was related to activities performed daily at work, including onscreen object manipulation and text appearance using Microsoft Word. The scroll task consisted of 10 possible tasks that involved manipulating onscreen script, pictures, tables and images (for full list of activities and instructions refer to Appendix B). The scroll task was carried out on a screen with a resolution of 1024 x 768. To begin, each task was set to a default font of "Times New Roman" set at size 12. Each task required the participant to use only one hand on a neutral mouse with the inner button set as the primary button. The scroll task required the individual to use the tool bars located on the top of the windows screen with emphasis on not using key short cuts on the keyboard. The dependent measure was the number of fully completed tasks at the end of 60 seconds. Timing began when the participant opened the file and thus deemed ready. Since the task was based on the ability to perform the set instructions as quickly as possible, and not based on recollection of the procedures to complete the instructions, each hand performed the task once and each individual began using the preferred hand.

Results

The primary goal of the study was to examine the differences in hand performance across tasks in order to select tasks for a training program in experiment 2. All the participants were considered to be right-handed individuals with an average Waterloo Handedness Questionnaire score of 41.67. In order to compare the tasks, laterality quotients were calculated to form a ratio of hand performance. The ratio was calculated using the difference between the preferred- and non-preferred hand scores divided by the total score of both hands for a value between -1.0 (non-preferred-hand superiority) and 1.0 (preferred-hand superiority). Each calculation was set up to show a positive ratio for a preferred-hand performance advantage. A one-way ANOVA was performed on the laterality quotients from all five tasks. Here, a main effect of task was found ($F_{(6,60)} = 27.52$, $p < .001$), where the laterality quotients varied as a function of the task being completed. A post-hoc analysis, done using a series of independent t-tests with a bonferroni correction, revealed that the line-crossing task had the largest positive laterality quotient, and hence had the greatest between-hand difference. The post-hoc analysis showed that the laterality quotients were relatively similar due to large variations in performance on the tasks. The line-crossing task was the only task to have a laterality quotient unique compared to all the other tasks, whereas the other four were statistically equal to at least one other task. For example, post-hoc analysis showed that the scroll task was the only task to measure as a slightly negative laterality quotient, however, it was considered statistically equal to the Annett Pegboard and Grooved Pegboard Remove phase due to a large standard deviation.

A better understanding of the results using the laterality quotients can be seen by examining the actual scores of the participants. The line-crossing rate of the preferred hand (0.35 lines/sec) far exceeded the non-preferred-hand rate (0.25 lines/sec). The scroll task was the only task that had a non-preferred-hand advantage when performing the task ($LQ_{scr} = -0.039$), though under a one-sample t-test was not significantly different from 0 ($t_{(17)} = -0.98$, $p = 0.343$). The scroll task under examination showed a very slight, non-statistical, completion difference of 3.95 tasks for the non-preferred hand versus 3.75 tasks for the preferred-hand. Figures 2a-2e show the actual differences between the hand performances when completing the tasks.

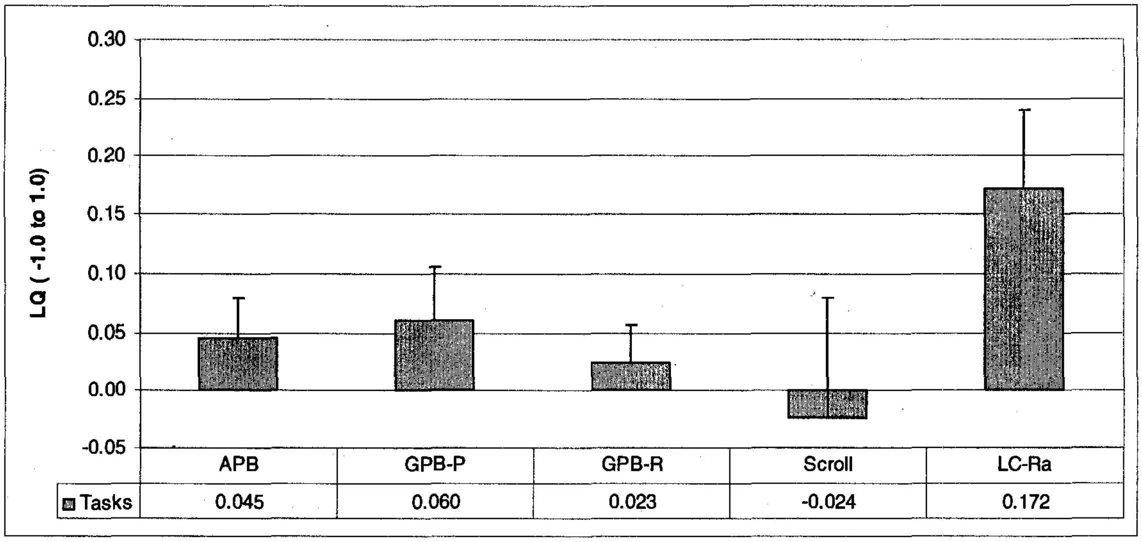


Figure 1: Study 1 Laterality Quotients by Task
APB: Annett Pegboard. GPB-P: Grooved Pegboard Place. GPB-R: Grooved Pegboard Remove. Scroll: Computer Scroll Task. LC-Ra: Computer Line Crossing Task Rates

A secondary goal of the study was to examine the correlation among tasks. The place phase of the Grooved Pegboard and the Annett Pegboard had a very strong positive correlation ($r_{(16)} = 0.70$, $p < .001$). The correlation shows that individuals who performed with a strong preferred-hand advantage for the Annett Pegboard were likely to score a strong preferred-hand advantage when performing the Grooved Pegboard. Unexpectedly, no other tasks were correlated (refer to Table 1 for Correlation Table).

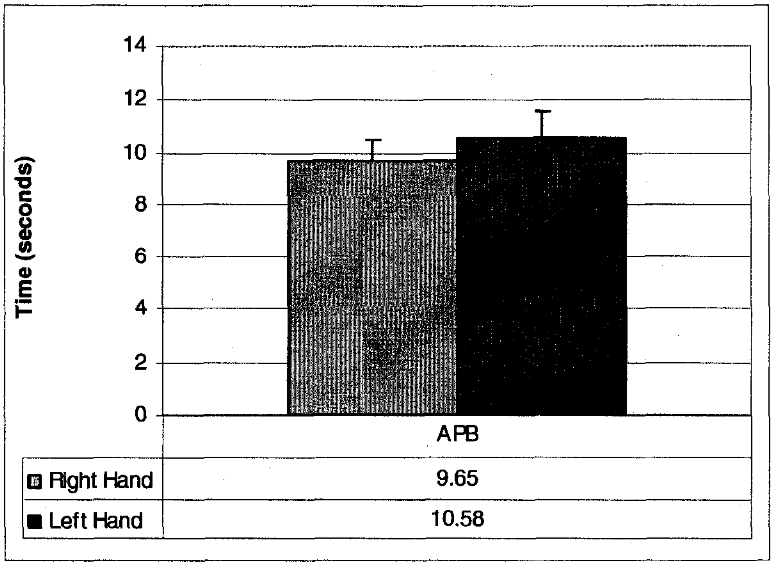


Figure 2a: Hand Comparison for the Annett Pegboard

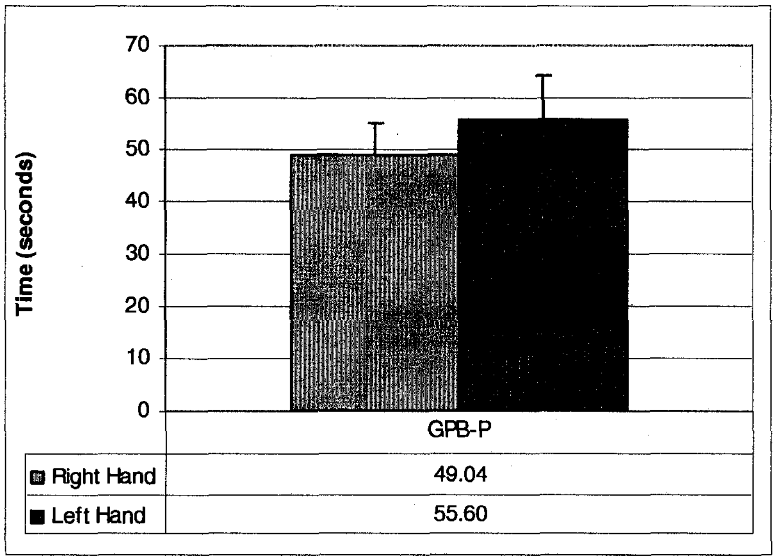


Figure 2b: Hand Comparison for the Grooved Pegboard Place

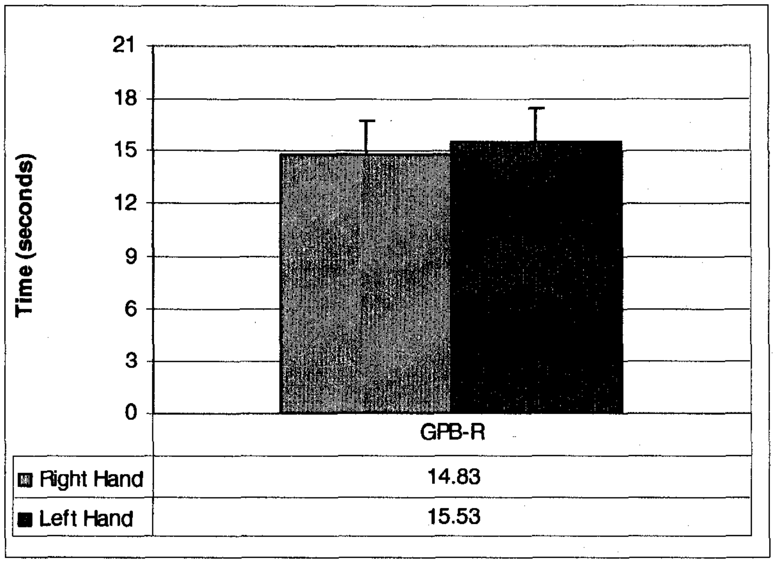


Figure 2c: Hand Comparison for the Grooved Pegboard Remove

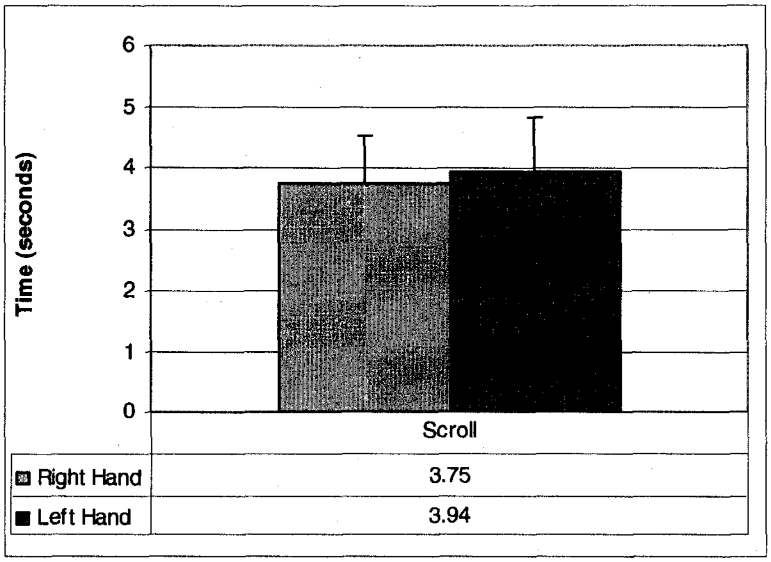


Figure 2d: Hand Comparison for the Computer Scroll Task

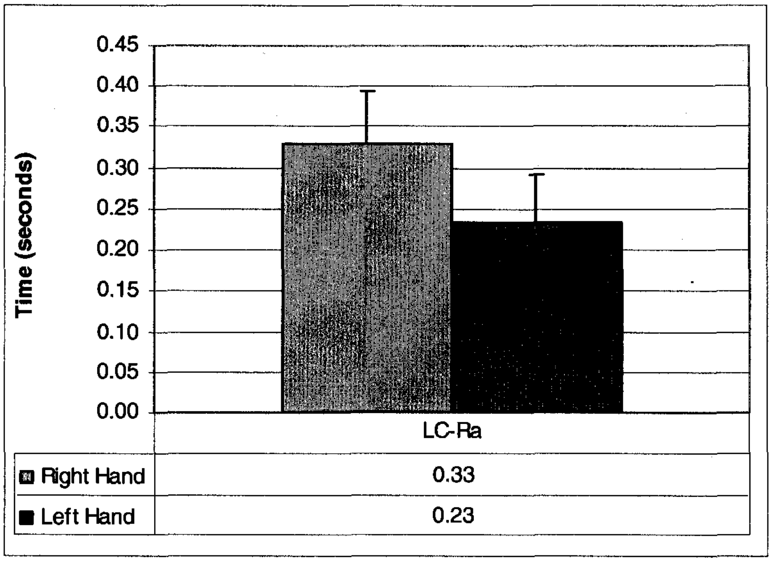


Figure 2e: Hand Comparison for the Line Crossing Task-Rates

Task	Statistic	WHQ	APB	GPB-P	GPB-R	Scroll	LC-Ra
WHQ	r p N		.060 .824 16	.188 .456 18	.274 .272 18	-.115 .650 18	.239 .340 18
APB	r p N	.060 .824 16		.704 .002 16	.472 .065 16	-.059 .829 16	.032 .906 16
GPB-P	r p N	.188 .456 18	.704 .002 16		.307 2.15 18	-.217 .387 18	-.163 .517 18
GPB-R	r p N	.274 .272 18	.472 .065 16	.307 2.15 18		-.090 .724 18	-.234 .35 18
Scroll	r p N	-.115 .650 18	-.059 .829 16	-.217 .387 18	-.090 .724 18		.158 .532 18
LC-Ra	r p N	.239 .340 18	.032 .906 16	-.163 .517 18	-.234 .35 18	.158 .532 18	

Table 1: Correlation Table of LQ by Task: r refers to the Pearson correlation coefficient; p values below α = 0.05 are significant; N refers to the number of participants included into the calculation.

Discussion

The purpose of the current study was to help establish which tasks would be used in the testing and training protocol for the second experiment, as well as how each task assessed skill differences between the hands. As expected from previous research, there were quantitative differences in the between hand performance for each task, though the similarities and differences were not quantified through any kinematic measures, like peak velocity or time to acceleration (Steenhuis & Bryden, 1989). The use of the laterality quotients demonstrated that each task showed preferred-hand advantage, with the exception of the scroll task, where there was no hand advantage found. The idea that most tasks brought a unique method to measure, yet similar experience to hand performance can be used to help randomize the training sessions to aid performance enhancements across both practiced and non-practiced tasks each session. In knowing that the tasks will measure individuals in a manner that is not statistically different across all other tasks, it can be reasoned that not all the tasks need to be practiced in every session in order for an individual to see a performance improvements.

The primary goal of the first experiment had been to examine how each task measured the performance differences between the hands of the study participants. Though some tasks shared similar components, the Grooved Pegboard and Annett Pegboard movement of pegs to different sets of holes and the computer tasks use of a mouse to complete commands, each had different levels of associated difficulty. As a result there was only one found correlation between the tasks in terms of the measure of performance discrepancy in the hands, the Grooved Pegboard Place phase and Annett Pegboard. The lack of significant correlations between the tasks meant that each task had different manipulative factors or associated skills sets, such as movement coordination, needed to complete the tasks. Though the tasks were not broken down into stages of movement, it can be inferred that each task would practice a different skill set if used in the training protocol, with the exception of the Grooved Pegboard Place phase and Annett Pegboard, which may share common components, because the tasks lacked any relationships when measuring the performance differences. The lack of correlations between performance tasks has been seen in previous works and could also reflect a lack of transferability of learned skills between performance tasks (Steenhuis & Bryden, 1989). In order to test this thought, new performance measures would need to be introduced following a training period in order to learn if there was any differences found between a performance training group and a no-training control group.

The single significant correlation provided evidence that the Grooved Pegboard Place phase and Annett Pegboard were similar enough to have associated scores of performance differences in the hands, and thus in the second study, the Annett Pegboard was removed and only the Grooved Pegboard Test (place phase) was kept as a training activity. In an attempt to maximize time efficiency for the training protocol the elimination of tasks was an essential goal of the study. The strong positive correlation between the laterality quotient of the Annett Pegboard and the Grooved Pegboard Place phase opened the choice of using one of the two tasks as a primary training task in the next study (Experiment 2). As such, the Grooved Pegboard Place phase was selected for a few reasons. First, the Annett Pegboard though performed faster had little manipulation of the pegs during the completion of the task. The lack of finger manipulations seemed to hold little transferable properties to hand movements in relation to a computer mouse, which involves hand movement while coordinating finger presses. Though the correlations were not significant between the Grooved Pegboard Place phase and the two computer tasks, they were stronger and both negative, indicating that the tasks were possibly involving different manipulation components of the hands, than between the Annett Pegboard and computer tasks. Secondly, the time required to complete the Annett Pegboard may be too short to enhance hand performance across other activities. The short trials, which required only 8-10 seconds, may lack the sensory input to make noticeable changes to the hand movements, whereas the 35-60 seconds required for the Grooved Pegboard may involve more attentional resources to complete the task.

Experiment Two: Long Term Training of the Non-Preferred Limb: Acquisition and Retention

The primary purpose of the second study was to examine how training could affect the acquisition and retention of skills in the non-preferred limb. More specifically, the study examined how a training protocol of differing lengths influenced the non-preferred hand performance on a battery of standardized and non-standardized tasks. A secondary purpose of the study examined if, and how, perceived comfort was altered following training programs of different lengths. Finally, a third purpose of the study was to investigate if the training improvements gained could be transferred to new skills following training, as well as retained over a period of no training experimental tasks, in the non-preferred hand.

Based on the conclusions of Ackland and Hendrie (2005), the study chose a 3-week training protocol of 3 days per week for 25-30 minutes a day, three different sessions done three times over the course of three weeks, as that was the determined time needed to see improvements. The experiment then compared the 3-week training group to a no training control group and a 1-week training group with three training sessions. The 1-week training duration, involving three different sessions done once each, was chosen because I wanted to learn if repeated exposure to the same sessions were needed to see improvements.

The examination of skill transfer between tasks was done using two new tasks: Finger Tapping and a Fitt's Law Task done on computer. Both of the tasks had been selected because of previous use in research studies that allowed for predictable hand performance. Peters (1981) concluded that with finger tapping the preferred hand generally shares an advantage over the non-preferred hand by about 10% regardless of the speed of person tapping. This was due to large inter-tap variability in the non-preferred hand. It was assumed that if practice resulted in skill transfer, the 3-week training group would have a lower performance division between the two hands and the no-training control group would show a marked difference in hand performance.

The Fitt's Law task was a modified version of the task and done on computer. In general, the Fitt's Law task can predict hand performance based on the size of the targets used and the space between them, or in other words a speed-accuracy trade off. Higher difficulty tasks result in fewer movements over a period of time. The difficulty of a task can be calculated using, $ID = \log_2(D/W+1)$ where D was the distance between targets, W was the width of the target and ID was the index of difficulty. The current study used ID's of two and four and focused on the number of accurate taps made while using a computer mouse to click within two targets. This way tapping differences could be measured. It was predicted that if training transfer had occurred the 3-week training group would be able to tap more times with the non-preferred hand, relative to the preferred hand, whereas the no-training control group would have very large performance differences.

It was hypothesized that they long-term training could improve the performance of the non-preferred hand to such an extent that the performance gap between the two hands would decrease. As well, a single week of practice would result in the improvement in the non-preferred hand, though more practice would result in greater improvements. Secondly, the participants who received the greatest amount of training were expected to increase the perceived comfort rating upon completion of the tasks, though the most difficult of tasks would still result in a stronger performance advantage in the preferred hand. The performance enhancement seen in both experimental training groups was expected to be retained over the short retention period and be transferable to tasks that were similar in nature to the training protocol.

Method

Participants

A total of 56 participants participated in the study. Participants were assigned to one of three training groups: a control group which received no training of the non-preferred limb, a training group that received 1 week of non-preferred limb training, and a training group that received 3 weeks of non-preferred limb training. The no-training control group consisted of 20 participants (12 females and 8 males). The 1-week training group consisted of 21 participants (12 females and 9 males). The 3-week training group consisted of 15 participants (11 females and 4 males). Each individual was capable of performing all the study tasks with their non-preferred and preferred hand and had normal or corrected-to-normal vision for each session. Participants enlisted from the KP 261 research course were compensated for their time in the form of research credits accredited to the final grade, while all other participants completed the study free of compensation. The study received ethical clearance from the Wilfrid Laurier University Research Ethics Board.

Procedure

Each participant was briefed to the expectations and time required to participate in each of the study groups before testing began. At that time, participants were placed into one of three groups: control, 1-week or 3-week training. Upon placement in a group, participants completed the Waterloo Handedness Questionnaire followed by the first testing session. Figure 3 outlines the procedures followed for each training group. Before each testing session, and the initial training, a briefing was given about the tasks for each participant, though practice trials were not allowed. Testing sessions were counterbalanced for starting hand for each task however the order in which the tasks were given was maintained through the course of the study.

Three standard training sessions were performed once each week, and were based on the suggests of Ackland and Hendrie (2005). Figure 4 shows the session composition in the order of presentation to the participant. The training sessions were carried out three times per week, for a total of three sessions for the 1-week group or nine sessions for the 3-week group. Sessions lasted from 20-30 minutes with the same ratio of practice in the non-preferred-hand-to-preferred-hand performance for each training group participant.

Materials: Tasks Used in the Testing Sessions

Several tasks were used during testing periods, which occurred prior to training and following training, including: Annett Pegboard, Grooved Pegboard, Scroll Task, Line-crossing task, Fitts' Law Task, and Finger Tapping. A detailed description of each of the testing tasks follows.

Waterloo Handedness Questionnaire Hand preference assessment occurred on the first day of pre-training testing via the use the Waterloo Handedness Questionnaire (WHQ). The WHQ consisted of 32 items regarding preferred hand use for skilled and unskilled tasks. Each question was answered on a 5-point scale ranging from (-2) always left, (-1) usually left, (0) equal use, (1) usually right and (2) always right. Participants were instructed that activities that have single hand use of 95% or more were considered "always", between 75-95% was considered "usually" and less than 75% was considered equal use. The questionnaire was then summed to calculate a total score to ensure that each participant was a right handed according to the preference questionnaire.

Grooved Pegboard Test The Grooved Pegboard was selected for inclusion in the current study because it has been used in the pilot study. The pilot study procedure for both the Place and Remove phase of the Grooved Pegboard was maintained for the current study. Both the non-preferred- and preferred hand, for the remove and place phases, were used to calculate laterality quotients {(NP-P/NP+P)*100}}.

Annett Pegboard The Annett Pegboard assessed motor speed and accuracy with an emphasis on speed control and targeting ability and was selected for the current study because of its use in the pilot study. The procedure used for the task was maintained from the pilot study. Each hand performed the task three times and the times to completion were used to calculate laterality quotients {(NP-P/NP+P)*100}}.

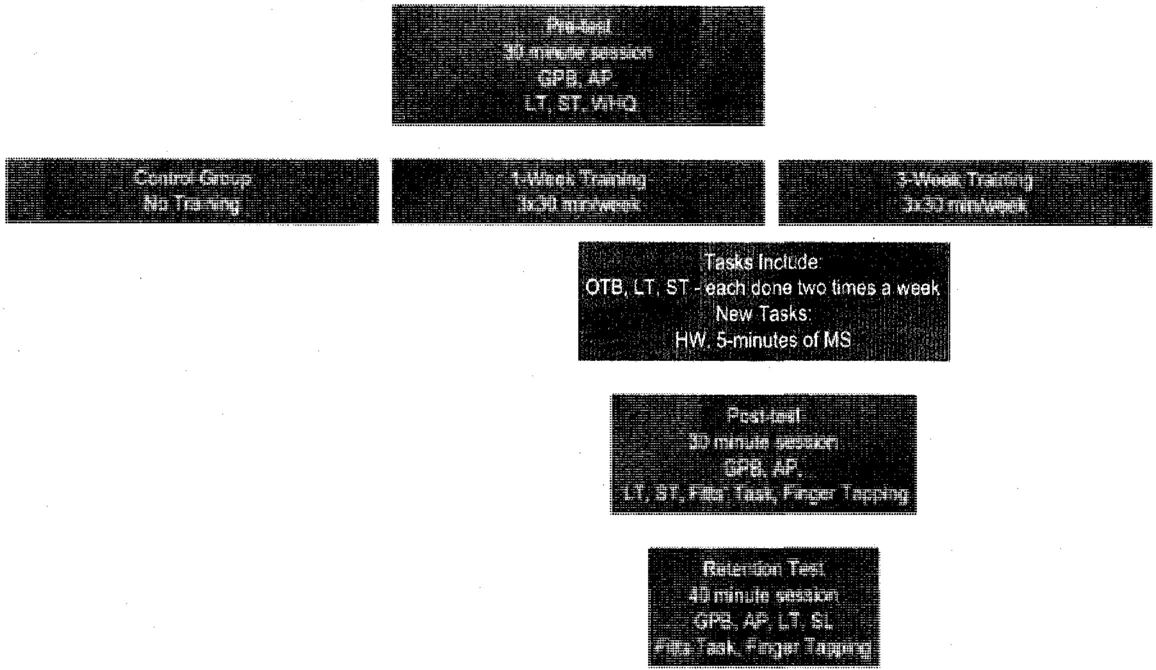


Figure 3 – Flow chart of study

Training Session 1	Training Session 2	Training Session 3
Handwriting Task – 1x RH & 3x LH Grooved Pegboard Place – 1x RH & 3x LH O'Connor Tweezer Dexterity Task – 1x LH 5-minutes of Minesweeper Scroll Task – 1x RH & 1x LH	Handwriting Task – 1x RH & 3x LH Grooved Pegboard Place – 1x RH & 3x LH O'Connor Tweezer Dexterity Task – 1x LH 5-minutes of Minesweeper Line-Crossing Task (30 seconds as many as you can) 1x RH & 3x LH	Handwriting Task – 1x RH & 3x LH Grooved Pegboard Place – 1x RH & 3x LH 5-minutes of Minesweeper Line-Crossing Task (30 seconds as many as you can) 1x RH & 3x LH Scroll Task – 1x RH & 1x LH

Figure 4: Weekly Training Schedule by Sessions – One of each training day would be completed each week for a total of three sessions per week.

Line-Crossing Task The line-crossing task assessed the ability to accurately manipulate a computer mouse to complete a series of tasks meant to mimic that of a simple graphics design or manual graphing function. The pilot study procedure for the line-crossing task was maintained for the current study. Each hand completed the line-crossing task three times and the completed tests were converted into rates of completion with the unit of lines/second. The rates were then used to calculate laterality quotients. Refer to appendix A for pictures of proper and improper completion of the task.

Scroll Task The scroll task was a non-standard computer task that had been used in the pilot study. The presentation and procedures for the completion of the task were maintained from the pilot study. The dependent measure was the number of completed tasks in a 60 second time limit. Since the task was based on the ability to perform the set of instructions as quickly as possible, and not based on recollection of the procedures to complete the instructions, each hand was given one attempt at the task.

Comfort Scale As in Ackland and Hendrie (2005), how comfortable an individual felt with each of their hands was assessed after each task. Participants were asked to mark down on a Likert scale ranging from (-2), not comfortable and unlikely to perform the task with the non-preferred hand if given the choice, to (2), very comfortable and likely to perform the task with the non-preferred hand if given the choice, indicating how they perceived their comfort and the likelihood that they would use that hand on a regular basis (for the full scale refer to Appendix C). After each completed set of trials for a task, individuals marked on the scale what their perceived comfort was for the task. These sheets were collected at the end of the trials and not viewed during any successive sessions. The dependent measure for the comfort scale was the marked score of perceived comfort following the completion of the task.

Finger Tapping The Finger Tapping task was a post-training and retention test task. The task was done on a finger tapping board which consists of a tap counter and finger pad. The finger pad was raised to 1" above and parallel to the tapping service. The board required the use of the index finger to push down onto the tap counter, registering a tap, and then allowed back to the starting position to validate the tap. Participants were given 10 seconds to tap as many times as possible, performing the task three times with both the non-preferred- and preferred hand. The number of counted taps was the dependent measure. The performance was averaged across trials and a laterality quotient was computed {(NP-P/NP+P)*100}}.

Finger tapping was selected as a post-training and retention test for its simple skill measure of hand performance. Previous work has shown that finger tapping is a quick and reliable measure of performance differences between the non-preferred- and preferred hand (Peters, 1981). The task was used in the post-training session to learn if there was a transfer in performance enhancement in the non-preferred limb immediately following training to new tasks. The test was used in the retention test session to learn if any noted training improvements were retained, or lost, over the course of a week of no training.

Fitts' Law Task The Fitts' Law Task was selected for the study because the skill required to manipulate the mouse to perform the task would require the individuals of the study to exhibit a high degree of control. The control exhibited would lend itself to how well an individual could use the mouse to perform while under pressure, which may be necessary in some work scenarios. The Fitts' Law Task was a computer task that was carried out on a computer. The task was a test of the speed accuracy trade-off in which participants used a mouse to click between two targets located on the screen as quickly as possible for 10 seconds. The task was carried out on a screen resolution set at 1024 x 768 and consisted of an index of difficulty of two and four. The index of difficulty two consisted of two targets that are 2.4 cm wide and set 2.3 cm apart. The index of difficulty four consisted of two targets 1.7 cm wide and set 11.6 cm apart. In both cases a small round curser, 0.5 cm in diameter, was the object seen on screen and clicked between the two targets. The task started after the participant clicked the start button and moved the cursor beyond a target bar. The task ended when the 10 second interval expired. The dependent measure for the task was the number of taps completed within the marked areas in the allotted time. Average times across trials as well as a laterality quotient were computed. Please refer to Appendix D for pictures of the actual task.

Materials: Tasks Used in the Training Sessions

During the training periods some of the testing tasks were used as training tools, including: Grooved Pegboard Place Phase, Line-Crossing Task, and Scroll Task. The protocols for administration of these tests remained the same for the training sessions. Several new tasks were also introduced during the training period, including: O'Conner Tweezer Dexterity Task, Handwriting Task and Minesweeper. More tasks were included into the training sessions in order to maximize the amount of movements practiced within a training session, while eliminating the redundancy of performing the same tasks each day. This was done in an attempt to limit participant drop out. A detailed description of each of the training tasks follows.

<u>O'Conner Tweezer Dexterity Task</u> The O'Conner Tweezer Dexterity Test (Lafayette Instrument #32021) was used as a training device due the complex nature of using tweezers to pick up and manipulate small pegs. The O'Conner Tweezer Dexterity Task assessed fine motor control and the ability to manipulate tools to complete a task. The task was comprised of a small board (29.4 cm by 14.7 cm) with the top half (14.7 cm by 14.7 cm) consisting of a peg-slot area and the bottom half containing a circular receptacle (12 cm in diameter) that contained 100 pegs (2.5 cm long). The set of tweezers with the board was 13 cm in length and an aperture of 1.5 cm when not squeezed. Each peg was placed into a slot 0.16 cm in diameter, separated by 1.1 cm between holes, by a set of tweezers and moved in a contralateral to ipsilateral from top to bottom fashion. Using only the tweezers, participants were required to pick the peg up from its receptacle located at the bottom of the board and insert it into the correct hole. Participants were

asked to complete the task as quickly as possible. The dependent measure of the task was the time required to place all 100 pegs into the peg-slots on the board. During the training period participants were required to perform this task only once and with the non-preferred hand due to the time required to complete the task. The task was not included in the final analysis of the data.

Hand Writing Task The hand writing task was used to compliment fine motor training in the hands. Participants were required to write the passage "I am writing with my non-writing hand" three times on a piece of paper to start each practice session with the non-preferred hand. Participants were allowed to write at their own set pace but were required to print the sentence. The writing was done with a medium tip Papermate blue pen on a standard 8"x11" piece of lined paper. The participants were instructed to keep all writing between the lines and legible. The hand writing task was only performed by the non-preferred hand and was not used in the final analysis.

Computer Minesweeper The computer minesweeper game was used as a training task in which participants used only the non-preferred hand to play. The participants played on the intermediate level that consisted of 16 x 16 playing area. The object of the game was to uncover 40 "bombs" on the field of play. Participants used the mouse to click and reveal what was located under a blank square or mark what they thought to be a "bomb". The game was a timed event and was carried out for 5 minutes in duration. If participants completed the game, or lost, before the 5-minute time limit, a new game was started. No data was taken from the task, however at the end of the 5 minutes a comfort rating was obtained. The task was also used to help control the possibility of boredom by participants while completing the training period.

Results

Group Comparisons by Task: Does Training Improve Performance?

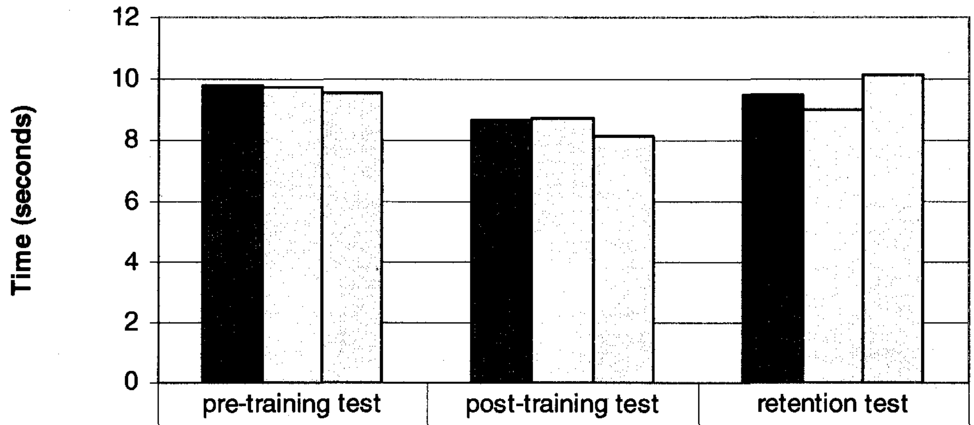
The main purpose of the study was to examine how different lengths of training affected the acquisition and retention of skills to increase hand performance. After the initial analysis for the task comparisons, the 1-week training group was removed from the analysis as they were not significantly different from the no-training control group on any tasks throughout testing. The 1-week training group also lacked improvements over the course of the study. A 3 (Testing Session: Pre-training, Post-training and Retention) by 2 (Hand) by 3 (Trial) between 2 (Group: No-training control group and 3-week training group) repeated measures ANOVA was performed for all the tasks, except the Finger Tapping and Fitts' Law Task. A 2 (Testing Session: Post-training and Retention) by 2 (Hand) by 3 (Trial) between 2 (Group: No-training control group and 3-week training group) repeated measures ANOVA was used for the Finger Tapping and Fitts' Law Tasks as these tasks were performed only during the post-training and retention testing. All post-hoc analyses for the repeated measures ANOVA's were done using a series of independent t-tests with a bonferroni correction.

<u>Annett Pegboard</u> The Annett Pegboard was a standard task not used during the training phase of the study and thus any improvement seen in the task was due to a transfer of skill from the trained tasks. There was a main effect of Testing Session ($F_{(2, 66)} = 6.68$, $p = .002$) in which there was a significant improvement shown during the post-training (9.62 ± 0.13 s) and retention (9.65 ± 0.14 s) tests versus the pre-training test (9.95 ± 0.11s). Though the majority of training had been completed with the non-preferred-hand, it appeared that both hands showed significant improvement when completing the task

for the second and third time. A main effect of Hand ($F_{(1, 33)} = 61.95$, $p < .001$), showed a preferred-hand advantage throughout the course of testing. In addition, a significant main effect of Trial ($F_{(2, 66)} = 9.42$, $p < .001$) was also found revealing a practice effect. Since the Annett Pegboard was a novel task for the participants, an initial learning curve was expected. After the first trial the variability in participants' scores decreased.

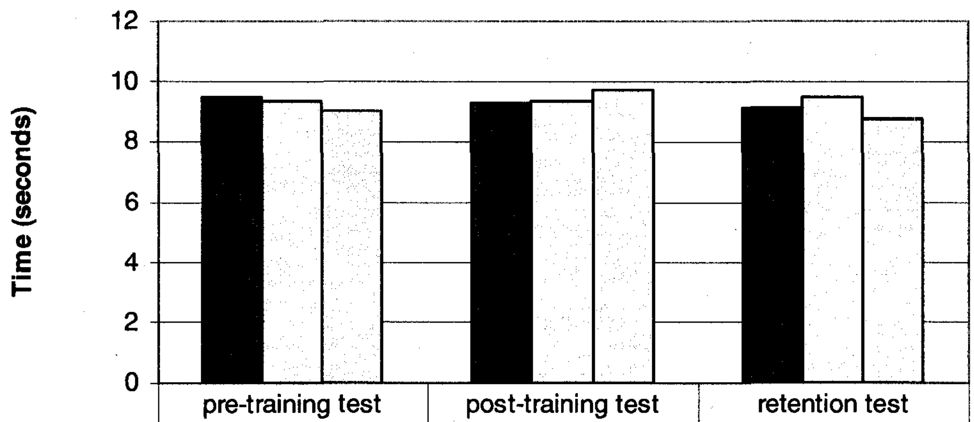
Analysis also revealed a significant interaction between Testing Session and Trial ($F_{(4, 132)} = 8.01$, $p < .001$), which showed that after the pre-training test of the Annett Pegboard the participants averaged similar times throughout the trials. Despite the time between the tests, both groups maintained their comparable scores across the trials in later testing sessions whether it was five days or three weeks until the Annett Pegboard was presented again.

When determining if the improvement seen over the course of the tests was due to training or a practice effect it was noted that there was no significant between group differences. Regardless of the training performed by the 3-week experimental group, both the 3-week group and the controls improved the score posted after the initial test. Figures 5a-b graph individual trial by trial results for the Annett Pegboard.



	pre-training test	post-training test	retention test
Trial 1	9.81	8.68	9.50
Trial 2	9.74	8.75	9.00
Trial 3	9.56	8.13	10.13

Figure 5a: Subject from No-training control group Annett Pegboard results by trial and testing for the non-preferred hand.



	pre-training test	post-training test	retention test
Trial 1	9.50	9.28	9.15
Trial 2	9.35	9.35	9.50
Trial 3	9.03	9.75	8.78

Figure 5b: Subject from the 3-week training group Annett Pegboard results by trial and testing session for the non-preferred hand.

Grooved Pegboard Place & Remove Task Unlike the Annett Pegboard, the Grooved Pegboard Place task was used for both the testing and the training portions of the study. Any between group differences were attributed to the training undergone by the experimental group versus the controls. Analysis revealed a main effect of Group ($F_{(1, 33)}$

$= 11.32$, $p < .001$) where the 3-week training group (46.15 ± 1.18s) was faster at completing the task than the control group (51.42 ± 1.03s). The improvement due to training was supported by examining the main effect of Testing Session ($F_{(2, 66)} = 36.89$, $p < .001$), which showed a decline in the time needed to complete the Grooved Pegboard Place Task from pre-training test (51.39 ± 0.84s) to post-training test (47.32 ± 0.81s) and retention test (47.64 ± 0.87s). A significant interaction between Testing Session by Group ($F_{(2, 66)} = 5.55$, $p =.006$) showed that under post-hoc analysis a large portion of the improvement was attributed to the experimental training group. Figure 6 compares the control and experimental group for overall movement time collapsed across hand.

Though the 3-week training group performed slightly faster (3.55 s) than the no-training control group at pre-training testing for peg placement, the post-training test times showed the performance gap had nearly doubled (7.04 s) between the two groups. During retention testing the difference in the overall performance for the Place phase than declined to a 5.22 s advantage for the 3-week training group. The improvement was the effect of the repeated exposure of the Grooved Pegboard Place Task by the experimental group.

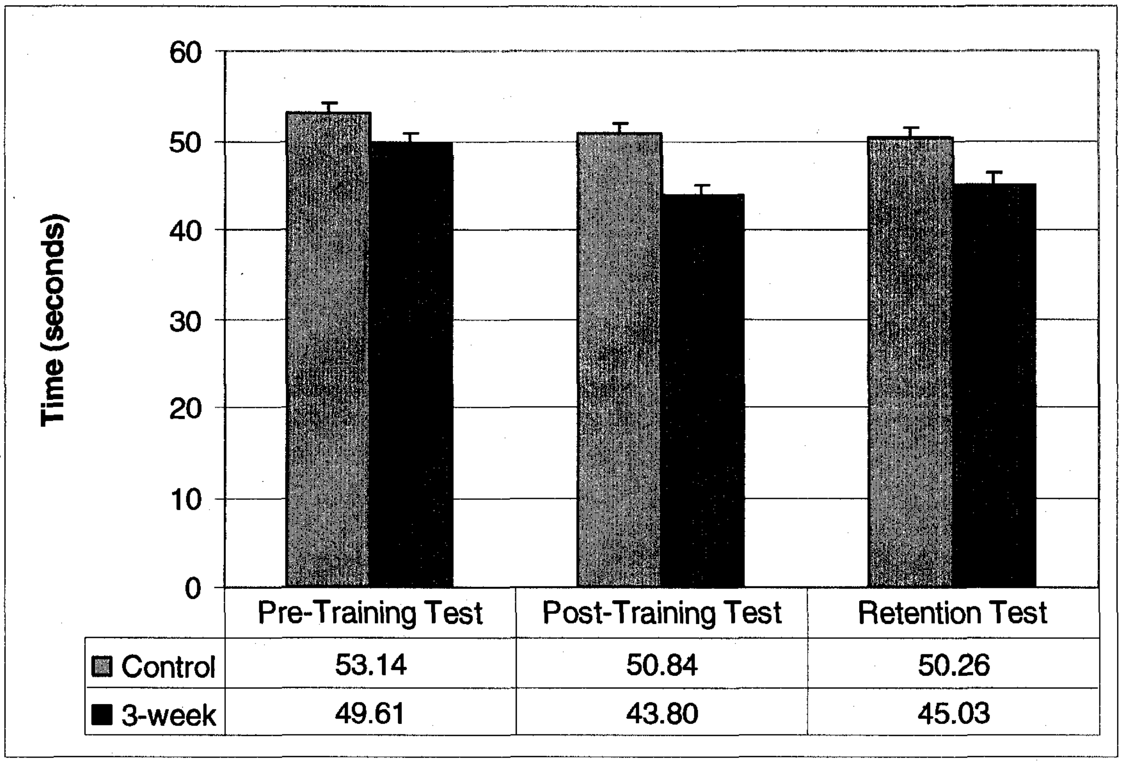
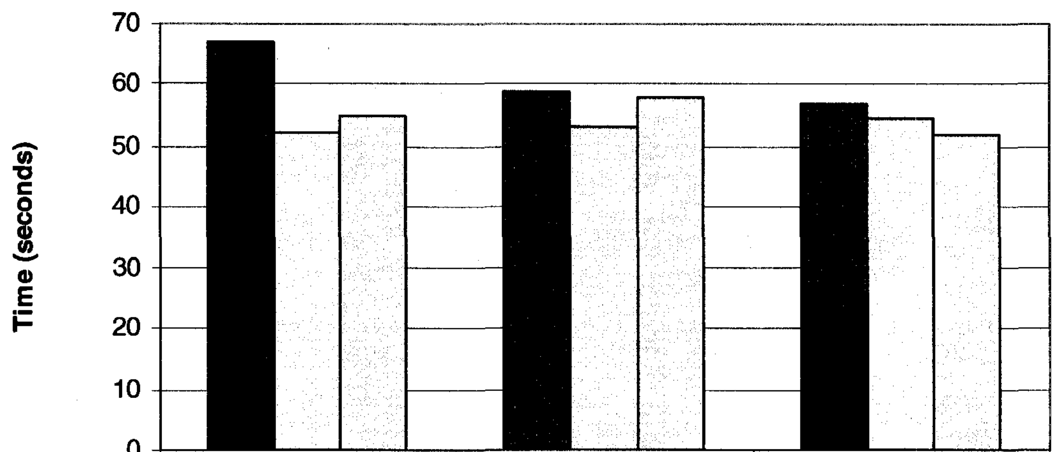


Figure 6 – Group by Testing Session comparison of the Grooved Pegboard Place phase. There is a significant difference between the tests where the training group outperforms the control group when completing the task.

The analysis also revealed a main effect of Trial ($F_{(2, 66)} = 25.43$, $p < .001$), where there was a significant decrease in the time required to perform the task after the first trial. Participants required approximately 2-2.5 s more to complete the placement of pegs on the first trial versus the second and third.

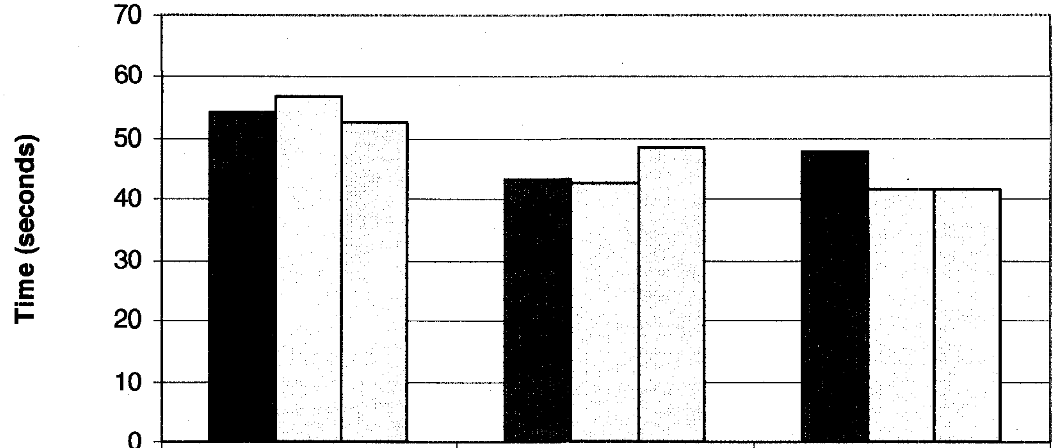
Interestingly, there was a significant Trial by Group interaction ($F_{(2, 66)} = 5.13$, $p = .009$), where differences emerged between the two groups. Here, the 3-week training group improved after trial one, and then showed equivalent performance in the second and third trials, while the control group improved across all trials. The improvements narrowed the performance gap between the groups. An interaction between Testing Session and Trial ($F_{(4, 132)} = 16.32$, $p < .001$) indicated each group steadied the variation in performance from trial to trial with successive tests. In the pre-training testing session, both groups varied in time required to place the pegs each trial. In post-training testing and retention testing, these variations decreased between trials, especially in the 3-week training group whom showed no trial to trial differences in performance. Figures 7a-b show the individual trial-by-trial results across tests for an individual in the no-training control group and 3-week training group.

A main effect of Hand ($F_{(1, 33)} = 132.89$, $p < .001$) indicated a large preferred-hand advantage to complete the task. A significant Testing Session by Hand interaction ($F_{(2, 66)} = 5.95$, $p = .004$) showed that though the preferred-hand advantage was maintained across all testing sessions, it was the non-preferred hand which had the greater improvement. More specifically, the non-preferred hand movement time decreased by 4.61 s while the movement time of the preferred hand improved only 2.88 s between pre-training testing and retention.



	pre-training test	post-training test	retention test
■ Trial 1	66.88	58.96	56.75
□ Trial 2	52.34	53.38	54.47
□ Trial 3	54.97	57.84	51.93

Figure 7a: A subject from the no-training control group performance across trial and test with the non-preferred hand for the Grooved Pegboard Place phase.



	pre-training test	post-training test	retention test
■ Trial 1	54.15	43.23	47.84
□ Trial 2	56.81	42.72	41.78
□ Trial 3	52.63	48.62	41.78

Figure 7b: A subject from the 3-week training group performance across trial and test with the non-preferred hand for the Grooved Pegboard Place phase.

The Grooved Pegboard Remove task was unlike the Place task in that it required far less peg manipulation when completing the task. The Remove Task simply required the participant to displace the peg from the slot and into a receptacle, reflecting a task similar to the Annett Pegboard. As such, the task was left out of the training protocol. However, like the Place task, the Grooved Pegboard Remove task showed that over the course of the study the times to complete it were improved (main effect of Testing Session - $F_{(2, 66)} = 7.44$, $p < .001$). Regardless of the hand, the average time to complete the Remove portion of the Grooved Pegboard decreased in duration from pre-training test to post-training test, and plateaued between post-training test and retention test. A main effect of Trial ($F_{(2, 66)} = 4.38$, $p = .016$) under post-hoc showed that after the first trial (16.12 ± 0.74s) there was an improvement to trial two (14.86 ± 0.29 s) that was not present between trial two to trial three (14.41 ± 0.27s). Like the Annett Pegboard, there were no between-group differences.

Computer Tasks: Scroll & Line Crossing The two computerized tasks were non-standard tasks used to determine if training of the non-preferred limb could increase its performance on computer tasks requiring the use of a mouse. Both tasks were used in the training and testing phases of the study.

The Scroll task was noted to be the easiest of the tasks for the non-preferred-hand to perform as the laterality quotient was slightly negative, which meant a nominal non-preferred-hand advantage during the pre-training testing. Recall that the dependent measure on the Scroll task was number of completed tasks within the 60-second time limit. Unlike all the other tasks used in the study there was no significant difference found between the hands, however, performance did get significantly better by testing session ($F_{(2, 66)} = 78.67$, $p < .001$). More specifically, participants increased the number of tasks completed from 4.03 ± 0.12 at pre-training testing to 5.22 ± 0.13 post-training and 5.44 ± 0.13 at retention testing. In addition, there was a main effect of Group ($F_{(1, 33)} = 5.88$, $p = .021$), where the 3-week training group (mean = 5.16 ± 0.16) completed significantly more tasks than the control group, (mean= 4.63 ± 0.14).

There was a significant Group by Testing Session interaction ($F_{(2, 66)} = 7.10$, $p = .002$). Figure 8 shows the differences between the control group and the 3-week training group as a function of testing session. To note was the rate at which the two groups improved across the testing sessions. More specifically, the training group showed a very large performance increase from pre-training testing (4.00 ± 0.19) to post-training testing (5.70 ± 0.19) but then plateaued at the retention test (5.72 ± 0.20). The control group, on the other hand, showed repeated improvements at each test (from 4.00 ± 0.16 at pre-training testing to 4.74 ± 0.17 at post-training testing to 5.16 ± 0.17 at retention).

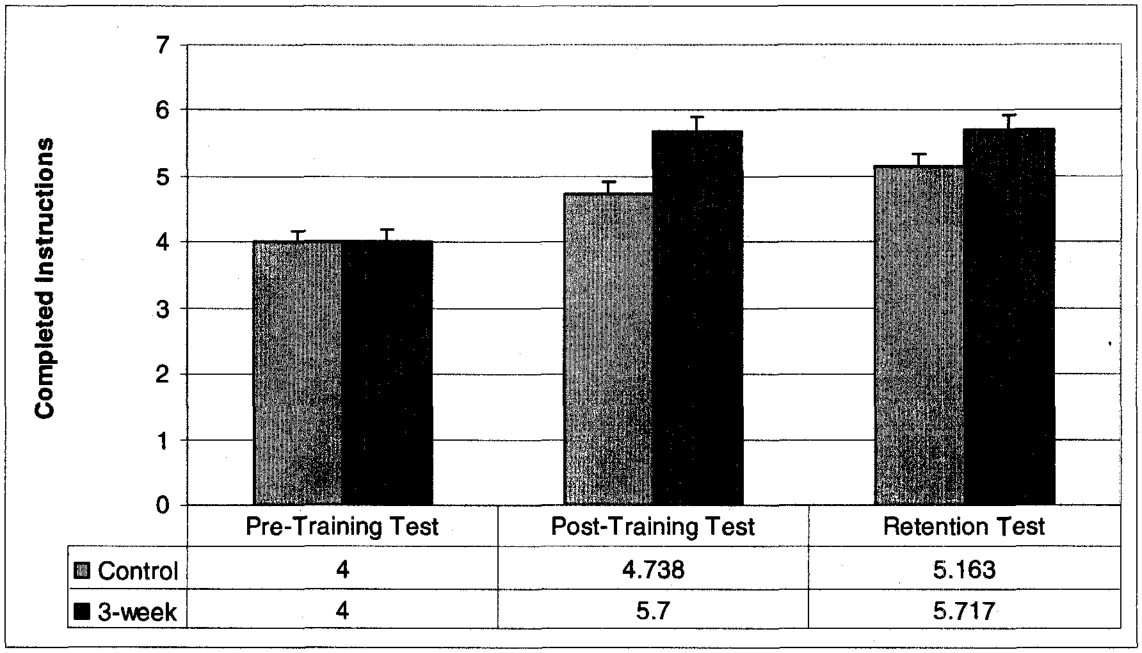


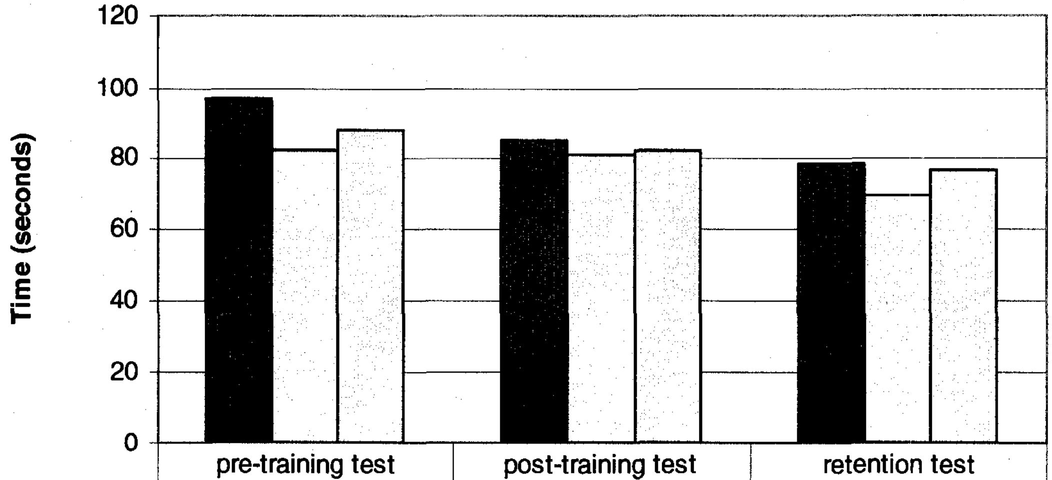
Figure 8 – Testing Session by Group graph for the Scroll Task. The group comparisons show that there was dramatic improvement in the 3-week training group performance during the post-training test that was far greater than that of the control.

The Line-Crossing Task was a much more difficult task requiring a large degree of manual steadiness and concentration by the participants. To eliminate the very large variation in completion times between the hands and participants, the total time to complete the task was converted into a rate of completion in order to compare the task without violating statistical rules. The conversion of the total times to rate ensured that scores of relatively fast participants could be compared to those who were relatively slow without violation the assumptions of ANOVA. If the raw data was compared, the within group and between group variations were so large that negative completion times were included. As such, lower rates were an indication of slower completion times as it meant less lines were being crossed per second.

There was a main effect of Testing Session ($F_{(2, 66)} = 43.26$, $p < .001$) where the completion rates were higher at the post-training testing (0.34 ± 0.02 lines/sec) and retention test (0.34 ± 0.02 lines/sec) verses the pre-training testing (0.282 ± 0.01

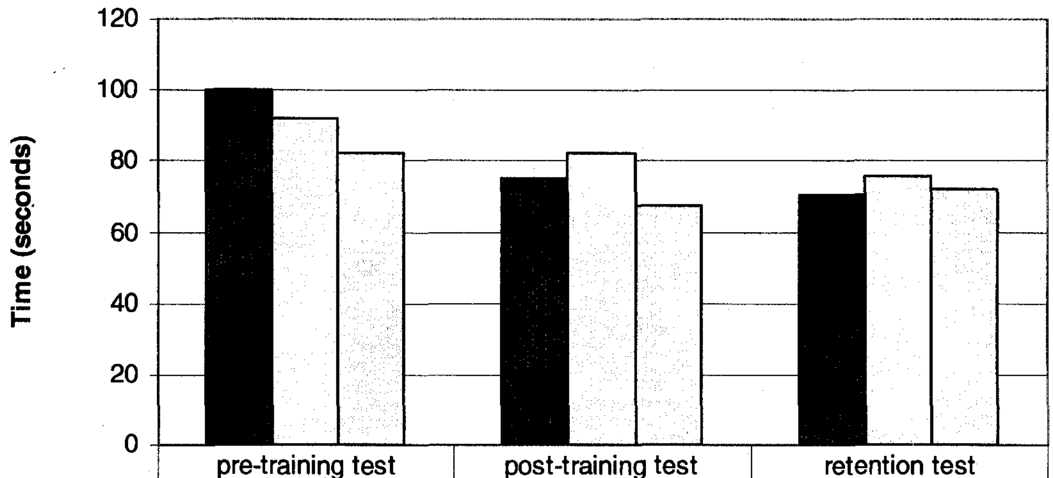
lines/sec). An expected main effect of Hand was also present ($F_{(2, 66)} = 225.55$, $p < .001$) where the preferred hand completion rate of 0.37 ± 0.02 lines/sec was significantly higher than the non-preferred hand completion rate (0.27 ± 0.01 lines/sec). A main effect of Trial ($F_{(2, 66)} = 10.35$, $p < .001$) was also found. Here, participants were significantly faster at completing the connections between lines in the second and third trials than the first. In addition, a significant Testing Session by Hand interaction ($F_{(2, 66)} = 3.44$, $p = .038$) revealed that the preferred-hand advantage was maintained across all testing sessions, with a greater improvement between tests for the preferred hand.

Though there was no between group differences to indicate learning, a significant Trial by Group interaction ($F_{(2, 66)} = 7.15$, $p = .002$) was found, showing that the two groups differed in performance across trials. The performance of experimental training group was relatively consistent across trials, whereas the no-training control group made significant improvements in performance with successive trials. This can be seen in Figure 10. The analysis also revealed a significant Testing Session by Trial interaction ($F_{(4, 132)} = 4.35$, $p = .002$). At the pre-training and post-training tests participants had improvements in performance across trials, whereas at the retention test there was no difference between the trials. Figures 9a-b graph the actual times to complete using the non-preferred hand of the individuals by trial across the testing sessions.



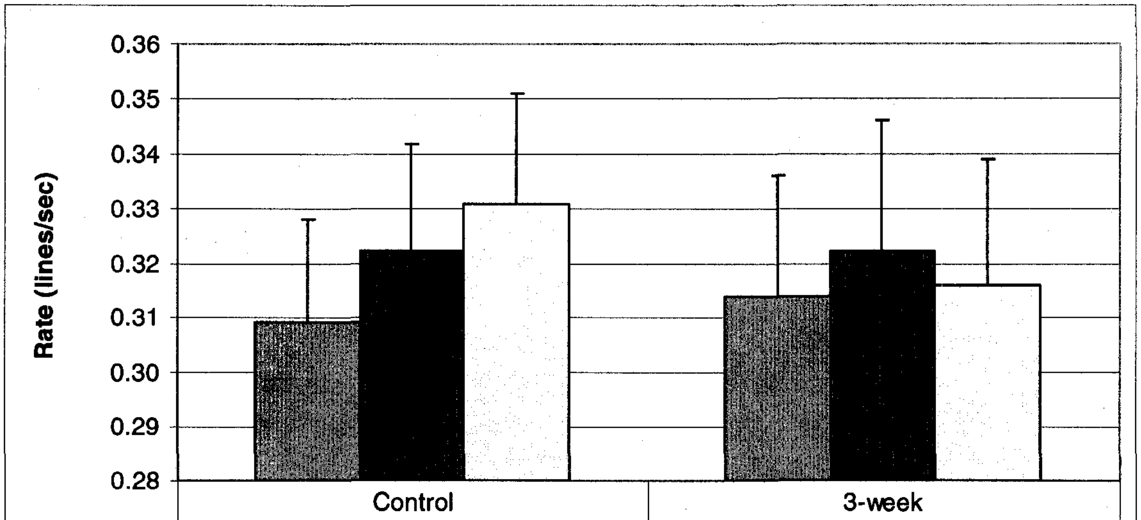
	pre-training test	post-training test	retention test
■ Trial 1	97.18	84.97	78.03
□ Trial 2	82.25	80.88	69.53
□ Trial 3	88.00	82.16	76.81

Figure 9 a: A subject from the no-training control group performance time required to complete the line-crossing task by trial and test with the non-preferred hand.



	pre-training test	post-training test	retention test
■ Trial 1	99.48	75.16	70.58
□ Trial 2	91.61	82.41	75.68
□ Trial 3	82.31	67.66	72.17

Figure 9 b: A subject from the 3-week training group performance time required to complete the line-crossing task by trial and test with the non-preferred hand.



	Control	3-week
Trial 1	0.309	0.314
Trial 2	0.322	0.322
Trial 3	0.331	0.316

Figure 10 – Line-crossing rate by trial for each group. There was a difference in how the groups performed between trials. The controls became significantly faster by trial while the 3-week group remained consistent each trial.

<u>Finger Tapping & Fitts' Law Task</u> In order to examine if the newly acquired skills of the non-preferred hand could be transferred over to new tasks, the Finger Tapping Task and Fitts' Law Task were added to the post-training and retention test of the study. It was assumed if there was a transfer of skill, the two groups, 3-week training verses no-training, would differ in the performance between hands as a result of the training. In other words, the laterality quotients would be lower for the 3-week training group due to the sessions of non-preferred hand training. The additional training would have resulted in a greater transfer to the non-preferred hand for completing the new tasks of the training group participants versus the no-training controls.

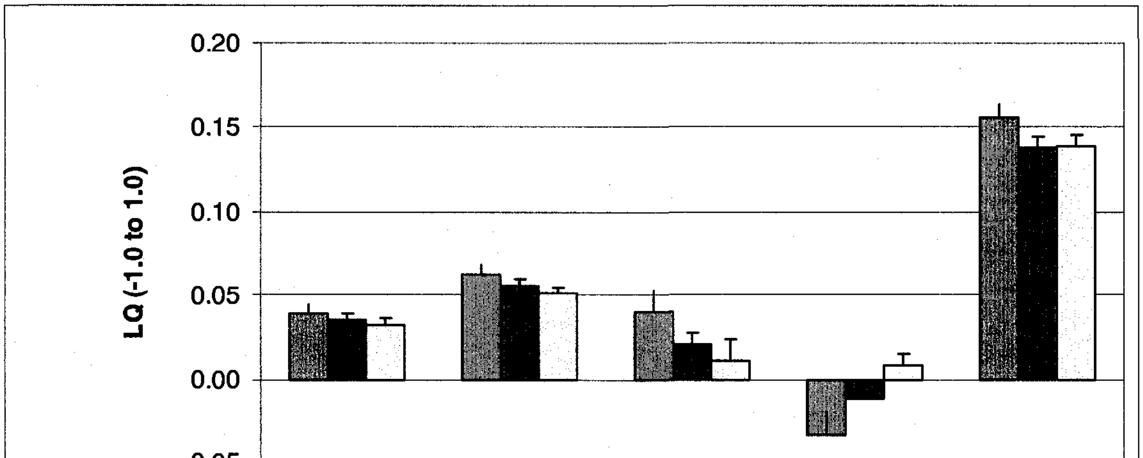
The Finger Tapping task was the final task for each participant and was completed in three 10-second trials. Analysis revealed a main effect of Hand ($F_{(1, 33)} = 72.92$, $p < .001$) where the preferred hand performed more taps (approximately 53 taps) than the non-preferred hand (approximately 49 taps). A significant Testing Session by Hand interaction ($F_{(1, 33)} = 7.90$, $p = .008$) indicated that the preferred-hand advantage increased between the post-training and retention tests. During the retention test, the preferred hand averaged 2.5 fewer taps than during the post-training testing, whereas the non-preferred hand did not change in its performance of approximately 49 taps. A significant interaction between Testing Session and Trial ($F_{(2, 66)} = 4.78$, $p = .012$) illustrated a consistent performance between trials during the testing, with the exception of the first trial between the post-training and retention tests. A significant Hand by Trial interaction ($F_{(2, 66)} = 6.40$, $p = .003$) found that though both hands were comparable in performance between most of the trials, the first attempt of the preferred hand tended to be slower at tapping then subsequent trials.

Two different difficulty levels, ID 2 and ID 4, were examined using the Fitts' Law task (refer to methods for description of each indices of difficulty). Thus, a 2 (Testing Session) by 2 (Difficulty: ID of 2 and ID of 4) by 2 (Hand) by 3 (Trial) between 2 (Group) repeated measures ANOVA was conducted. No main effect of Testing Session or Trial was found. However, there was a main effect of Difficulty ($F_{(1, 33)} = 488.03$, $p < .001$), where the easier task, ID of 2, had more than double the number of taps than the more difficult task, ID of 4. The trend of better performance for the easy task was maintained between the experimental group and controls as indicated by the interaction between Difficulty and Group ($F_{(1, 33)} = 4.85$, $p = .035$). A main effect of Hand ($F_{(1, 33)} = 202.98$, $p < .001$) was present in that the non-preferred hand performed significantly worse (12.04 ± 0.40 taps) than the preferred hand (18.12 ± 0.46 taps). A significant interaction between Hand and Difficulty ($F_{(1, 33)} = 27.72$, $p < .001$) under post-hoc analysis showed that in both the ID of 2 and ID of 4, the preferred-hand outperformed the non-preferred hand, but there was significantly more taps being performed during the ID of 2. A Hand by Trial interaction was also present, where the performance of the non-preferred hand varied between trials, whereas the preferred hand remained comparable between trials ($F_{(2, 66)} = 4.54$, $p = .014$).

Performance Differences by Tasks and Tests: Laterality Quotients

The main objective of the current study was to examine if long-term training would improve the non-preferred limb performance on a battery of tests. In order to compare the tasks the laterality quotients were computed, where the difference between the preferred- and non-preferred hand (in time or count) divided by the sum of the preferred- and non-preferred-hand for all tasks. Figure 11 indicates the laterality quotients for each task of the five tasks: Annett Pegboard, Grooved Pegboard (Place and Remove Phases), Scroll Task and Line-crossing Task, by testing session for the groups. A 3 (Testing session: pre-training, post-training and retention) by 5 (Task) by 3 (Group) repeated measures ANOVA was performed to examine how the laterality quotients varied across experimental groups and if scores changed by tests. A main effect of Task was present ($F_{(4,212)} = 147.97$, $p < .001$) in that all laterality quotients were significantly different from each other, with the exception of Grooved Pegboard Remove and Scroll Tasks which were equivalent.

A significant interaction between Testing Session and Task was also found ($F_{(8,424)} = 3.10$, $p = .002$) which indicated a learning effect for two of the tasks. The post-hoc analysis, done using a series of independent t-tests with a bonferroni correction, when controlling for testing session, showed that the Grooved Pegboard Place task resulted in a decrease in the laterality quotient, from 0.063 at the pre-training test to 0.051 at the retention test, while the Scroll Task resulted in an increase in the laterality quotient, from -.0034 at the pre-training test to 0.008 at the retention test. Improvements were seen in both the non-preferred and preferred hand over the course of the study for the Grooved Pegboard Place phase; however, there was a dramatically larger improvement in the non-preferred hand. At the pre-training testing, the non-preferred hand took approximately 55 seconds to complete whereas at the retention test the same task required only 50.03 seconds, an improvement of nearly 5 seconds. In contrast the preferred hand increase had an improvement of just over half of the non-preferred hand, at 2.88 seconds from 48.84 seconds to 45.26 seconds.



	APB	GPB-P	GPB-R	Scroll	LC-Ra
Pre-Training Test	0.039	0.063	0.04	-0.034	0.156
Post-Training Test	0.035	0.056	0.021	-0.012	0.138
Retention Test	0.032	0.051	0.011	0.008	0.139

Figure 11: Laterality Quotients by Tests for each Task - APB: Annett Pegboard. GPB-P: Grooved Pegboard Place. GPB-R: Grooved Pegboard Remove. Scroll: Computer Scroll Task. LC-Ra: Computer Line Crossing Task Rates

The Scroll Task improvements were of a different trend, in that the preferred hand had a larger improvement across the testing sessions. On average, participants improved their preferred hand performance by 1.55 tasks from the pre-training test to the retention test, whereas the non-preferred hand improved on average only 1.29 tasks. Though the absolute difference seems minimal, the importance revolves in the change in the laterality quotient value. At the pre-training test, the average participant demonstrated a non-preferred-hand advantage for completing the task (LQ = -0.034), whereas at the post-training test the LQ decreased (-0.012) and at the retention test a preferred-hand advantage was present though only slight (LQ = .008). In general, both the Grooved Pegboard and the Scroll Task had a larger performance increase in one hand over the other resulting in changes to the hand performance ratios.

The analysis of the laterality quotients also revealed no difference among experimental groups. Despite the differences in the reported Waterloo Handedness Questionnaires scores, there were no differences between the hand performance ratios for the experimental groups at the pre-training test. An average across tasks showed an equal preferred-hand advantage across all experimental groups. Thus, any changes within a group were attributed to the practice completed by that experimental group.

Transfer of training was examined using the new tasks introduced in the post-training test and retention test (Fitts' Law Task ID 2 and ID 4 and Finger Tapping). If training transfer had occurred it was expected that the calculated laterality quotient for the training groups would be smaller, indicating equal performance between hands, than that of the no-training control group because the training would have improved the non-preferred hands ability to perform any task, not just the training tasks. A 2 (Testing Session: Post-training and Retention Test) by 3 (Tasks: Fitts' Law Task (ID 2 and ID 4) and Finger Tapping) between 2 (Group: No-training control group and 3-week training group) repeated measures ANOVA was performed examining the calculated laterality quotients for the tasks. All post-hoc analyses were done using a series of independent t-tests with a bonferroni correction. The 1-week training group was removed from the analysis as they were found to have no statistical difference from the no-training control group.

There was no main effect of Group or Testing Session, indicating that the groups did not improve, nor were they disadvantaged, for taking part in the training protocol. Instead, like the original five testing tasks, there was a main effect of Task ($F_{(2, 66)} = 90.37$, $p < .001$) where the tasks all differed in the measured performance differences between hands. Each group performed the task equally regardless of the training. For these tasks the Finger Tapping was the easiest task followed by the Fitts' Law Tasks, where the most difficult level, ID of 4, caused the greatest differences between hands.

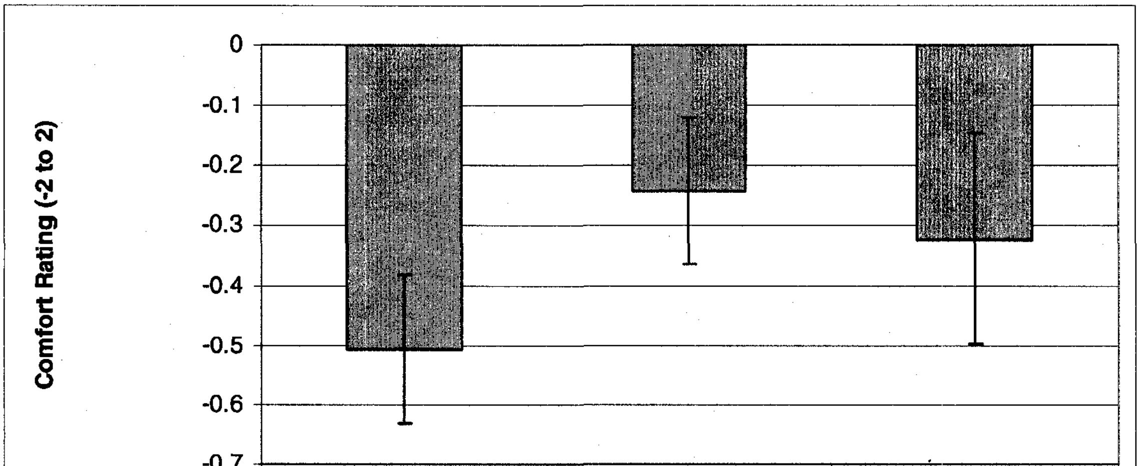
Comfort Analysis The comfort scale was a subjective measure of how the participants perceived the performance of the non-preferred hand as a substitute for completing the task with the preferred hand (refer to Appendix C for the comfort sheet). For the study, a number between (-2) and (-0.1) was an indication that the non-preferred hand felt awkward with little to no control while completing the task. A number from (0.1) to (2) was an indication that a participant felt the non-preferred hand was under control while completing the task. The scale was not an indication that an individual preferred one hand over the other but instead the perceived comfort and control in using of the non-preferred hand. Numbers approaching 0 from the negative were an indication that the participant no longer felt the non-preferred limb was out of control while completing the task. For the comfort rating analysis the 1-week training group was included because it was of interest to learn if 1-week of training increased the participants' perceived comfort in using the non-preferred limb despite lacking performance improvements in the task. To analyze how the comfort ratings changed over the course of a study a 3 (Testing Session) by 5 (Task) between 3 (Group) repeated measures ANOVA was conducted.

A main effect of Testing Session ($F_{(2, 92)} = 6.23$, $p = .003$) was found. Post-hoc analysis revealed that the average scores across the tasks at the post-training session were closer to 0 than at the pre-training session, indicating that the participants felt the non-preferred hand was a useful. Figure 12 illustrates the increased comfort rating. The change in comfort was an indication that the participants felt that the non-preferred hand was under more control and easier to use, as seen by a smaller negative average score, at the post-training test in comparison to the pre-training test.

As expected there was a main effect of Task ($F_{(4, 184)} = 57.18$, $p < .001$) where multiple tasks were noted to have different perceived ratings of comfort. Post-hoc analysis of the Task main effect found that nearly all of the tasks had unique recorded measures, though only two, the Annett Pegboard and Grooved Pegboard – Remove Task, actually received a positive rating. A positive rating for completing the two tasks meant that participants believed if given the option they would use the non-preferred hand to complete the task, as it felt easy to use and controllable when performing the task.

To compare the comfort scores on the Fitts' Law Task (ID of 2 and ID of 4) and the Finger Tapping Task, a 2 (Testing Session) by 3 (Task) between 3 (Group) repeated measures ANOVA was performed. There was no main effect of Testing Session or Group, indicating that all three groups in the experiment perceived the level of comfort in the non-preferred hand to be the same. There was a main effect of Task ($F_{(2, 100)} =$

99.99, $p < .001$) where the Finger Tapping was perceived to be the easiest and most comfortable to perform, whereas the Fitts' Law task (Index of difficulty of 4) was considered to be the most uncomfortable and difficult to perform. There was a significant Testing Session by Group interaction ($F_{(2, 50)} = 3.50$, $p = .038$) where the 1-week training group had a lower perceived comfort level in performing the new tasks as opposed to the control group at post-training testing.



	Pre-Training Test	Post-Training Test	Retention Test
Comfort Score	-0.508	-0.242	-0.322

Figure 12 – Comfort by Testing Session. The comfort scores decreased for the post-training test however went back up after a retention period. Note that the overall scores never reach a positive score, indicating that difficult tasks were perceived to be more uncomfortable than the easy tasks were comfortable.

General Discussion

The main purpose of the current research was to examine the effects of long-term training on the non-preferred hand and if training affected the perceived comfort of using that hand. As expected, there was a successful demonstration of improved performance by the participants over the course of the study, as well as an improvement in comfort. Though the study did not reach the level of expected performance of the non-preferred hand, the overall improvement in the level of comfort the participants perceived following training in the non-preferred limb was an excellent step to showing that perception of comfort in performance does not always equate to the actual performance.

The current study was based largely on the premise of two prior studies examining long-term training and performance differences between the hands for computer mouse use (Ackland & Hendrie, 2005; Peters & Ivanoff, 1999). While Peters and Ivanoff (1999) were more interested in the quantitative differences of left-mouse users versus right-mouse users, they demonstrated that individuals performed virtually normally when using the mouse in the non-preferred hand. Ackland and Hendrie (2005) performed a similar study examining how long-term training affected the non-preferred hand performance in individuals who work with computers. The study concluded that 30-minute training sessions done three days a week over the course of three weeks would significantly improve the proficiency of the non-preferred hand.

Though these studies were highly successful, neither study looked at the perceived comfort of the individuals when they performed the tasks. Nor did either study use standard tasks of performance measures for handedness to learn if these individuals in fact performed better with the preferred hand on a battery of tasks. In doing so, the Peters and Ivanoff (1999) and Ackland and Hendrie (2005) would have increased practical and theoretical value of their studies and thus the secondary aim of the current study was to measure the perceived comfort of individuals following the completion of a task. The current study also used standard tasks of performance measures of handedness to ensure that the individuals were in fact right-handed.

Effects of Training

The training program was created to focus the majority of training to the non-preferred hand of individuals as well as introduce tasks that might be used by an individual in a given day. Unlike previous work, the training program was not created solely on the repeated exposure of the same task in an attempt to improve the performance (Heath & Roy, 2000), but instead on a group of tasks, some used during testing and some not, in an attempt to improve the performance. In this the study was successful; however, was the improvement an effect of repeated exposure and thus a practice effect, or was there actual learning occurring?

A practice effect can be considered an immediate improvement after initial exposure to a novel task. Such improvements are not indicative of learning, but instead a reflection of a participant's unfamiliarity with the test. A study examining a test-retest reliability of motor assessment using a stylus found an excellent example of a practice effect (Broeren, Sunnerhagen, & Rydmark, 2007). Here, the individuals had to identify objects with a stylus in a virtual environment, but the unfamiliarity with the task had participants experimenting with how they performed the task. The experimentation with how the participants completed the task had individuals consistently improving through the first half of trials before beginning to perform consistently with a fixed strategy. Most studies that involve repetitive testing procedures of performance are bound to have practice effects, however it is important to note if there is an overall improvement over time that is retained.

This was the case of the current study. Not only did participants improve scores across testing sessions, but after the pre-training testing differences between trials were reduced and in some cases were completely eliminated. Performance on the Annett Pegboard was an excellent example of these between-trial performance similarities. More specifically, after the pre-training testing, participants were noted to have a dramatic drop in performance after the first trial, however there was no such trial effects in post-training or retention testing. The lack of trial effects indicated a consistent performance, because of learning; either by the adoption of a fixed strategy or by the adaptation to the task. This was supported by the retention of improved scores during the retention test. Had the training produced no learning, the performance would have matched the findings of Noguchi, Demura, Nagasawa and Uchiyama (2005), where participants performed a pursuit rotor test that resulted in significant improvements after each successive trial. During the pursuit rotor test, the authors noted that because the test was unfamiliar the improvements were due to gaining experience and not learning, or in other words a practice effect.

Though the current study failed to show improved performance across all the tasks, two that did were the Scroll Task and the Grooved Pegboard Place phase. The between-group differences for both tasks suggest that learning had occurred as both showed performance advantages for the training group. The current study replicated the results of Ackland and Hendrie (2005) in that the non-preferred hand actually exceeded the preferred hand after training and after a 1-week retention period for the Scroll Task. The difference between the current study and Ackland and Hendrie (2005) was that there was a no-training control group to compare to for the task. The inference of learning comes from the drastic improvement in performance by the 3-week training group's post-training test results in comparison to the pre-training test, which was then retained over the course of a week with no training. The score plateaued between the post-training and retention test for the 3-week training group, whereas the no-training control group had minimal improvement each testing session with the Scroll Task. Learning is marked by stages of gains and plateaus where during the periods between plateaus, reorganization occurs to develop new strategies (Magill, 2003). The lack of differences between the 1-week training group and no-training controls indicated that three training sessions were not enough to establish a strategy to improve performance, whereas the nine training sessions allowed the 3-week group to develop a strategy with the non-preferred hand to improve performance.

The Grooved Pegboard (place phase) further supported the argument that learning had occurred. The trial by testing session interaction showed consistency in performance between trials for the latter testing sessions of the study. The task required a high degree of manipulation by the hands in response to visual input. As such, it would be expected that the non-preferred hand would perform more poorly and inconsistently than the preferred hand of a right-handed individual (Roy & Elliot, 1986). Yet the non-preferred hand, though it performed at a slightly slower rate, was consistent in performance after the training period, and showed a larger overall improvement in time than the preferred hand. The performance improvement is likely due to more efficient use of the visual feedback from the eyes to the hand resulting in less corrective movements being needed during the last portion of the task. Previous work on feedback response has provided evidence that as the hands become practiced they become more adept to using the visual and non-visual cues (Heath & Roy, 2000). In the case of the current study, with the repeated practice trials, the participants adjusted to using the visual, seeing the actual orientation of the peg in reference to the peg hole, and non-visual cues, proprioceptive feedback of the limb in relation to the target area, to properly orient the peg while targeting to fit into the peg-slot enabling them to be more efficient and consistent when completing the Place phase of the Grooved Pegboard.

Yet, besides the training, why were the improvements seen in only two tasks were not completely understood. Examining theories of performance differences in hands may help explain why this occurred. Flowers (1975) described two types of motion, ballistic, which consists of fast sequential movements free of conscious control, and corrective motion where the movement is constantly under moderation and are slower in nature. In order to see practice improvements, Flowers (1975) believed that thousands of trials were required to improve ballistic movements, something not done in this study, while corrective motion takes considerably less practice since it is always under conscious control. When examining the Grooved Pegboard Place phase the actual movements can be broken into three parts, picking up the pegs (ballistic), moving the peg towards the hole (ballistic), and orienting the peg while placing it into the hole (corrective). Following the nine training sessions, the experimental training group had learned to quickly adjust incorrect movements in the orienting and aiming portion of the pegboard improving the corrective aspect of the task.

The same explanation can be used for the Scroll Task. During its completion the hand motions were continuously monitored and corrected, to ensure the proper information was highlighted and operation selected. Each task consisted of multiple corrective movement phases, as the normal keyboard short cuts and toolbars had been eliminated. Following the training protocol, individuals were better adapted to smoothly control the mouse to select the text and operations needed to quickly complete the tasks.

The three remaining tasks that did not show any improvements over the course of the study could provide evidence of task-dependent learning. The Annett Pegboard and Grooved Pegboard (remove phase) did not improve in the overall performance from one testing session to the next. The performance on the two tasks was more consistent in the latter two tests, but the overall time did not improve across the tests. The training sessions lacked a task that practiced speed and the removal of the pegs. The lack of training did not allow the participants to improve on the corrective aspects for these tasks as it did the Scroll Task and the Grooved Pegboard Place phase. An additional activity with the corrective aspects could have been used by participants involved in training to develop a strategy to complete the Annett Pegboard and Grooved Pegboard Remove phase more quickly.

The Line-crossing task was practiced during the course of the training period, however, like the Annett and Grooved Pegboard (remove phase) it did not show improvement post training. A probable cause for the lack of improvement was the way in which the task was practiced. In an attempt to improve the speed of the task completion, participants had been instructed to connect as many lines as possible within a 30 second time limit during practice. During testing session, the Line-crossing task was a time to complete task, where individuals were told to accurately connect all the lines as a timed task. Thus, the different instructions could have influenced learning on this task.

Another goal of the study was to determine if the training could influence the size of the between-hand performance differences. To compare the tasks, laterality quotients were created. It was found, however, that despite the focused training on the non-preferred hand, the preferred hand advantage was maintained throughout the course of the study. Thus, despite the dramatic improvement in the non-preferred hand for the Scroll and Grooved Pegboard Place phase tasks, and overall improvements on the other tasks, when compared at the same point in time the preferred hand was still outperforming the non-preferred hand on the testing tasks. Peters (1981) described this phenomenon when examining finger tapping. Finger tapping is a simple task which both hands are relatively equal at performing. Yet when both given ample practice, Peters (1981) demonstrated that for every practice advantage the non-preferred hand was given the preferred hand was able to maintain its advantage when completing the task. Thus, future research should compare the initial state of the preferred hand versus the current state of the non-preferred hand following training.

Transfer of Skill

A second goal of the study was to examine if the skills trained could be transferred to new task. To examine transfer of training, the Finger Tapping Task and Fitts' Law Task on the computer were examined. The training was not successful in transferring any learned skills to the new tasks. The notion was that if there was a performance transfer from the training, the between-hand differences for the groups would be different for the tasks post-training (Cassavaugh, 2007; Nyberg, Eriksson, Larsson & Marklund, 2006). By training the hands to perform skilled motor tasks, the experimental training groups would be initially better at performing the two new tasks. However, this was not the case, instead, participants from both groups performed at the same relative level while maintaining equal performance differences between the hands.

The lack of transfer is suggestive of task-dependent learning by the non-preferred hand. Thus, in order to see improvements for the non-preferred hand, one would need to specifically train that hand in the task it is required to do, otherwise, the hand may be less energy efficient and more susceptible to injury than if it were not used.

Despite a lack of transfer between tasks, there does appear to be intermanual transfer of skill. Intermanual skill transfer occurs when training focused on one hand results in improved performance in the opposite hand (Burgess, Bariether & Patton, 2007; Schulze, Luders & Janke, 2002; Parlow & Kinsbourne, 1989). The training protocol in this study focused on the non-preferred hand, where some tasks were only performed with the non-preferred hand. Yet, despite the focused training, there was enough gain in the preferred hand for a positive laterality quotient to be maintained in nearly all of the tasks. For the Scroll task on computer, the performance gap actually widened to produce a greater preferred-hand advantage. The apparent intermanual transfer can ensure individuals that while practicing to complete a task with the non-preferred hand, the other hand will not become handicapped when reverting back to its use as training results in improvements in both hands over time.

Comfort Analysis

A major reason the current study was performed was to establish how individuals perceived the non-preferred hand and how this perceived comfort might change with training. It appeared that training did not alone affect the comfort rating; however, repeated exposure to the tasks did, as it can be seen by the uniform improvement of perceived comfort by all three groups during the post-training tests. Thus, after the initial testing periods, the participants rated the tasks as more comfortable to perform. The results were similar to Peters and Ivanoff (1999) who asked participants how it felt to perform the mousing tasks with the non-preferred hand following an extensive testing period. When told that the movements felt awkward and clumsy but tolerable, the overall kinematics analyses revealed nearly equitable results. In the current study, performance differences between the hands were maintained but the non-preferred hand was no longer just tolerable in its use, but accepted as a possible substitute. Secondly, it was noted that not many of the actual comfort ratings correlated with better performance. In fact, only the Finger Tapping, Grooved Pegboard Place, and Annett Pegboard tasks actually had correlations between left-hand performance and perceived comfort. In each of those tasks, a better non-preferred hand performance resulted in a better comfort rating.

When examining the comfort on the transfer to new tasks, there was a negative relationship between the training and the perceived comfort by test. The average comfort on the new tasks for the 1-week training group was more likely to indicate a greater discomfort in the non-preferred hand when performing the tasks for the first time. However, the 3-week training group and controls were not different in the perceived comfort. The reason for this may be that the length of training for the 1-week training group left them in the midst of developing strategies for the trained tasks; however the strategies were not fully developed like the 3-week training counterparts. The lack of a proper performance strategy left this group unable to significantly improve their performance during testing and hindered the ability to adapt the hands to novel tasks. After one week of no activity, the developing strategy was likely forgotten and thus did not influence how they performed the task, resulting in a similar comfort rating to other study groups.

An important aspect of the perceived improvement in comfort was that it appeared to be a temporary effect. The main effect of Testing Session was only between the pre-training testing and the post-training test. Though participants showed improvements in performance from the pre-training test to the retention test, they did not rate the non-preferred hand as more comfortable. Often participants were heard saying "Oh I am no good at this" during the retention testing, though in fact they performed no differently than they had a week earlier during post-training testing. It was assumed that during the pre-training test that participants' based comfort on the actual performance differences between the hands. Practice was used to bring the attention to the actual movements of the hand in an attempt to improve performance. The lack of practice over the course of the week removed the familiar routine of using the non-preferred hand for the study participants and eliminated this train of thought. After a week of no activity, the participants' again focused on comfort as a result of performance differences between the hands, thus lowering the perceived comfort.

Hand Differences and Learning

Based on theories of handedness, there is one dominant hand when performing unimanual tasks, in that it performs faster, more accurately, and efficiently (Provins, 1997; Elliott & Chua, 1996; Annett, Annett, Hudson & Turner, 1979; Flowers, 1975). Though the theories do not agree why the differences between hands exist, each can explain the findings of the current study, but two theories appear to stand out.

Provins (1997) explained that experience in hand use was the reason why hand differences exist. When utilizing the same neuromuscular resources to complete a task, they become more efficient in their use. For this reason, three weeks of training resulted in greater performance by the experimental training groups on some of the tasks. The repeated performance of the Place phase of the Grooved Pegboard and the Scroll task allowed the hands to become more efficient in using the fingers to manipulate pegs and coordinate mouse strokes. According to Provins (1997), the reason that all of the tasks did not achieve improved performance was the lack of a proper procedure to exercise the neuromuscular units involved in those tasks.

An issue with Provins (1997) theory was that it could not explain why there was no transfer of skill for similar tasks during the current study. According to Provins (1997) when gaining experience in a specific activity, tasks with similar components and movements will be improved because of the shared neuromuscular activity. For example, to practice drawing by manipulating a pencil should then result in improved performance when using a pencil to handwrite. If this were true, then the style of practice used for the Line-crossing Task should have resulted in improvements during the testing of the Line-crossing Task regardless of the training and testing procedures. Instead there were no improvements between tests or the experimental groups.

In addition, Provins (1997) provides no explanation for the apparent intermanual transfer during the training period of the study. There as no available reason why after a non-preferred hand training period there was an improvement in the preferred hand. Here, the motor output hypothesis was relevant for the current study.

The motor output hypothesis examines goal directed movement based on previous work by Woodworth (1899) who examined manual aiming. From that work, it was concluded that differences between the hands occurred because of the ability to quickly respond to feedback to correct erroneous movements. This meant that differences were not because of the actual movements involved, as Flowers (1975) had suggested, but instead the motor functioning as moderated by the brain (Elliot & Chua, 1996). More specifically, it appears that the hemispheres of the brain have advantages for performing specific tasks. Though the two hemispheres are not independent entities, they do provide performance advantages of the hands for certain tasks, such as spatial orientation with the right hemisphere and voluntary movements by the left-hemisphere. This explains the results of the current study in greater detail.

According to a review by Elliot and Chua (1996), the left hemisphere, which controls the movements of the right-hand, is better at controlling movements of goal-directed aiming than the right-hemisphere, as it moderates movement errors more efficiently. Annett, Annett, Hudson and Turner (1979) determined that the majority of the differences were the result of incorrect movements and their corrections, during the last 10% of the movement, or the aiming phase. The current study, which consisted of all right-handed individuals, had improvements in the Grooved Pegboard Place phase for the non-preferred hand but all participants retained their preferred hand advantage. Similarly, the Scroll Task had improvements post-training that showed large non-preferred hand gains, but an increased preferred hand advantage. The inference was that these two tasks had improvements in the non-preferred hand because during the aiming portion of the tasks, orienting and inserting the peg for the Grooved Pegboard and mousing over the proper text and operation for the Scroll Task, there was better control over the corrective movements due to the training. More specifically, training resulted in fewer movements to compensate for initial movement errors that had the non-preferred hand off the target goal. The preferred hand advantage was maintained because the inherent ability of the preferred hand for aiming tasks and asymmetric transfer of training from the non-preferred- to preferred hand.

For the current study, despite training, the preferred hand advantage was maintained for all of the testing tasks. In the literature review, Elliot and Chua (1996) explained the preferred-hand performance gains as a result of the asymmetric transfer between the hands and motor overflow between hemispheres during training. More specifically, because the left hemisphere of the brain is heavily involved in the organization and coordination of timed muscular contractions, when the right-hemisphere is controlling movements for the left-hand, non-preferred hand for the current study, there is still activation in those motor areas of the left hemisphere. Since both of the tasks that showed learning consisted of very large aiming portions, it is likely there was plenty of neural activity in the left-hemisphere of the braining during training. As a result, while training the non-preferred hand, the timing and coordination mechanisms were being practiced to improve both the preferred- and non-preferred hands.

According to the review by Elliot and Chua (1996), training and testing procedure differences would result in different methods of execution, as different modes of motor functioning would be utilized. For this reason the Line-crossing Task did not have improvements over the course of the study. When training for the task, the focus for the line-crossing was on the speed aspect of the task, not the aiming, as the goal was to connect as many as possible. During the testing procedure, the focus of the participants was on the aiming portion for accurate completion. The two different methods practiced different methods of motor control and therefore had no transferable improvements.

Thus, the current study supports the motor output hypothesis, but accepts that the preferential experience did influence performance differences, for a few reasons. Training improvements seen in the two tasks that had learning appeared to show improvements during the aiming portion of the tasks. By training and testing the Line-crossing Task in two different ways, reliance on two different modes of coordination were utilized and no improvement seen. Finally, the preferred hand advantage was retained over the course of the study because of asymmetric transfer during training.

Limitations

The study was limited primarily by using only right-handed individuals. As noted earlier, a left-handed individual does have a tendency to be less lateralized than a right-handed individual. As such, these individuals would most likely react differently to a study protocol in training the non-preferred hand. Secondly, as Peters and Ivanoff (1999) noted with their study, left-handed individuals when using computers must develop one of two attitudes: use a mouse as it is positioned on the right side of a keyboard or, as only a few minority do, search out and use a left-handed mouse for a computer. The results of their study indicated that those who search out the left-handed mouse during some tasks perform differently then the right-mouse left-handed and right-handed counterparts. In order to properly assess the training protocol another two groups should have been added to the study.

A second limitation to the study was a lack of pre-training testing for the transfer tasks in the study. Without a set of comparative raw data before the training period for these experimental tasks, any transfer of training effects could only be assumed upon the study completion. A second reason for the need to include the pre-training testing measure was that with all the training occurring in the non-preferred hand, there appeared to be a significant improvement in the preferred hand of the training group participants. As such, when comparing the preferred- and non-preferred hand at the same point in time will rarely, if ever, show eliminates the relative difference in performance between the hands. In order to learn if there was a clear transfer of skill, future research must include untrained tasks to the initial testing period, and then use follow-up testing to learn if there were any training effects seen on those tasks.

A third limitation to the study was the wording for the comfort questionnaire questions. It was determined upon completion of the data collection the comfort scale was asking two different questions. The first half of the question asked the perceived comfort in using the non-preferred hand to complete the task, whereas the second half of the question determined the issue of usability of the non-preferred hand to complete the task. Without the asking of the participants, what determined the comfort score could have been a combination of either of these two questions. Future studies, there is a need to correct the phrasing of the question to ensure that the participants answering the questions of comfort understand clearly what is being asked.

A fourth limitation to the study was the time it required individuals to be involved. Data of individuals who stopped showing up to training sessions or testing sessions were removed. Data from individuals who failed to participate in the 9 training sessions within 21 days were removed, as it was deemed to be too large a down period between sessions to be comparable to the other groups. Though the dropout rate was limited in the numbers (only 4 participants were removed from study analyses) they were all from the 3-week training group. If these people had continued with the study, they may have strengthened or attenuated the effects of the study. No follow up could be obtained to learn why they had stopped showing up for the study sessions.

A second issue with the lengthy data collection period was that it negated the possibility of having a second retention test. The effects of training cannot be labeled as permanent changes in behaviour, as there was no test performed to determine if three months post-training there was still an increased improvement in task performance in both the hands. Future research involving long-term training would improve greatly from further retention period testing, as it serves no benefit to undergo a training period of any length, if the residuals of the training are lost after the cessation of use.

Conclusion

The study data supports that long-term training does train the non-preferred limb and with repeated exposure to a task there does appear to be an increased comfort in the use of that limb. However, the training does appear to be task dependent, and it is unclear whether the gains are maintained over long periods. For training to have a maximal influence on non-preferred hand performance a minimum of 3 training sessions must be done, with 75% of the training time dedicated to the non-preferred limb, and must be done in a relatively consistent manner; for example, every other day for approximately 30 minutes between 2- to 3-weeks. Individuals must also use the hand in the way it would be intended to use, as task dependent learning will limit the usability of the non-preferred hand.

Secondly, for comfort to change, an individual must continue to use the non-preferred hand. The individual should also accept that the hand will never be as developed and capable as the preferred hand but instead a replacement option at a level consistent to a beginner or novice at the task, however capable of vast improvement.

Appendix A

Below is a condensed version of the Scroll Task as it appears to participants. During the testing and practice phases of the study, all ten activities presented will be spread across five pages with only two tasks listed onto one page.

ALL TASKS MUST BE CARRIED OUT USING ONLY THE MOUSE!

1. Highlight and **BOLD** and increase text size to 24

Bold and Increase Text Size

2. Shade in the first and last columns of the table

Shade			Shade
Shade			Shade
Shade			Shade

3. Cut and Paste the Text below to the LETTER 'a' below

This text is to be cut and paste to the letter a

a.

4. Create a table with 4 columns and 4 rows using the following procedure: Table – Insert – Table – Using Mouse to click rows and columns to 4 from default

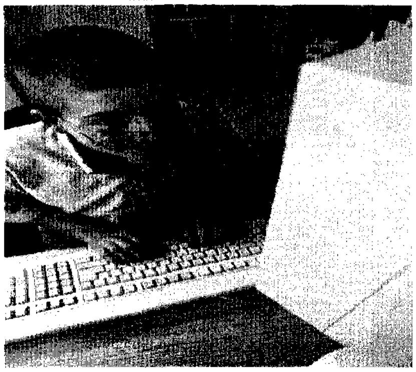
5. Highlight and *Italicize* and change the font colour to RED

Italicize and Change the Font Colour to Red

6. Rearrange the following sentence to read:
   I am completing a scroll task on a computer.

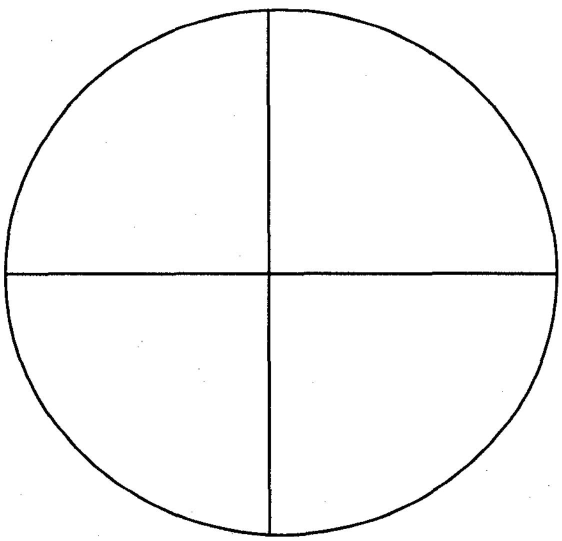
completing I am scroll computer. on a task a

7. Invert both pictures (90°)



8. Using the insert symbol function. Insert the following symbols below: (all symbols are adjacent to each other)
   ΣΤΥς

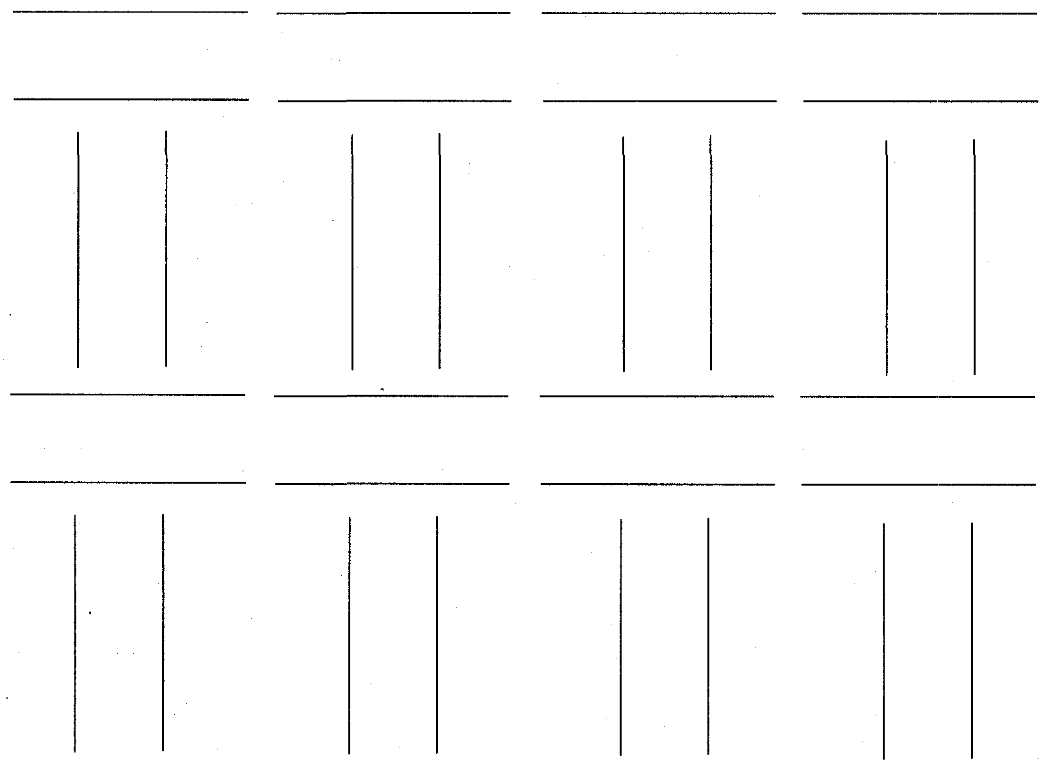
9. Using Autoshapes Create a cross using lines to match the one below



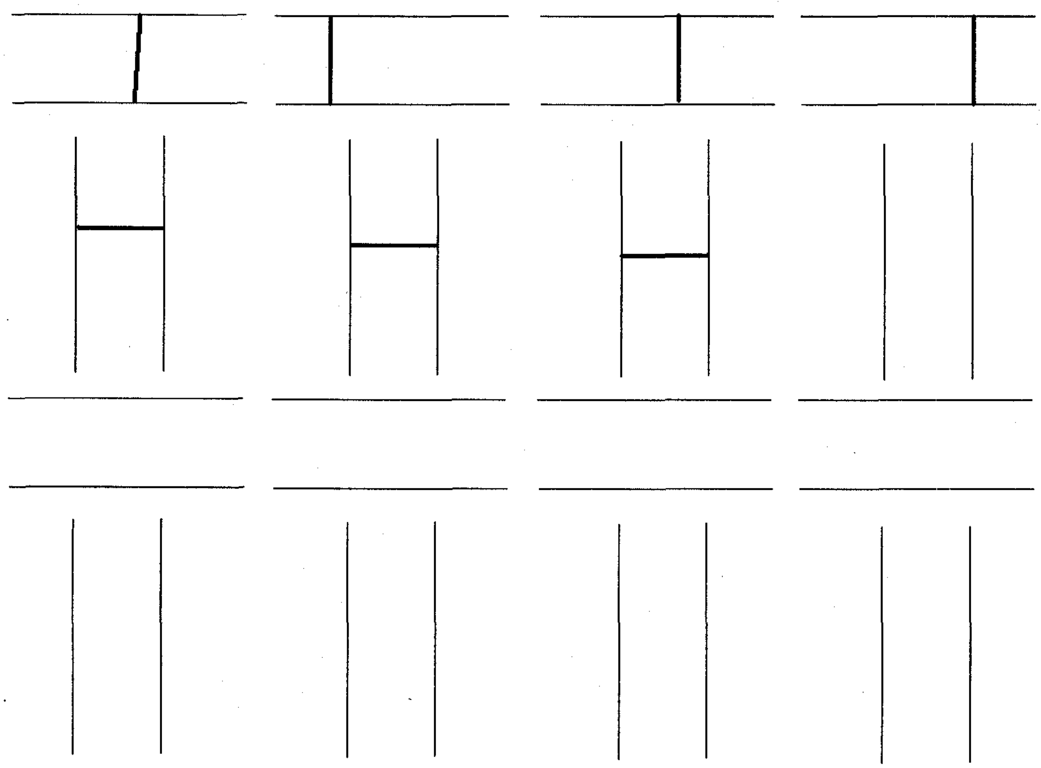
10. Go to File – Save as …. Stop. You're done.

Appendix B

Below is an attached insert of the Line-Crossing Task as it appears on screen on a smaller scale. The figure below is an unmarked version of the test. Participants must connect the parallel lines by creating a single line perpendicular between them. Flaws in the line will be considered an error and thus an incomplete connection.



Below is an example of a possible trial. Note that the first connecting line in the top left corner is considered "flawed" because it is not a perfectly straight line connecting the two parallel lines. Since the task has emphasis on accuracy, participants must maintain precise connections between the two lines as seen in the following connections.



Appendix C

Comfort Table - Testing

At the end of each task please mark how comfortable you were with using your non-preferred hand on the task. Any additional information not seen on the scale can be added in writing to the right of the scale. The number of scales are defined below:

(-2) – I was not comfortable using my non-preferred hand and would not use it as a substitute for the given task.

(-1) – I was somewhat uncomfortable using my non-preferred hand and would not consider not use it as a substitute for the given task.

(0) – I did not feel uncomfortable using my non-preferred hand and have no preference to using or not using this hand as a substitute for the given task.

(1) – I was somewhat comfortable using my non-preferred hand and would consider using it as a substitute for the given task.

(2) – I was comfortable using my non-preferred hand and would use it as a substitute for the given task.

Scroll Task

-2 -1 0 1 2

Line-Crossing Task

-2 -1 0 1 2

Grooved Pegboard Task

-2 -1 0 1 2

Annett Pegboard Task

-2 -1 0 1 2

O'Conner Tweezer Dexterity Task

-2 -1 0 1 2

Comfort Table - Practice

At the end of each task please mark how comfortable you were with using your non-preferred hand on the task. Any additional information not seen on the scale can be added in writing to the right of the scale. The number of scales are defined below:

(-2) – I was not comfortable using my non-preferred hand and would not use it as a substitute for the given task.

(-1) – I was somewhat uncomfortable using my non-preferred hand and would not consider not use it as a substitute for the given task.

(0) – I did not feel uncomfortable using my non-preferred hand and have no preference to using or not using this hand as a substitute for the given task.

(1) – I was somewhat comfortable using my non-preferred hand and would consider using it as a substitute for the given task.

(2) – I was comfortable using my non-preferred hand and would use it as a substitute for the given task.

Scroll Task

-2 -1 0 1 2

Line-Crossing Task

-2 -1 0 1 2

Fitts' Law Task

-2 -1 0 1 2

Handwriting Task

-2 -1 0 1 2

Minesweeper Task

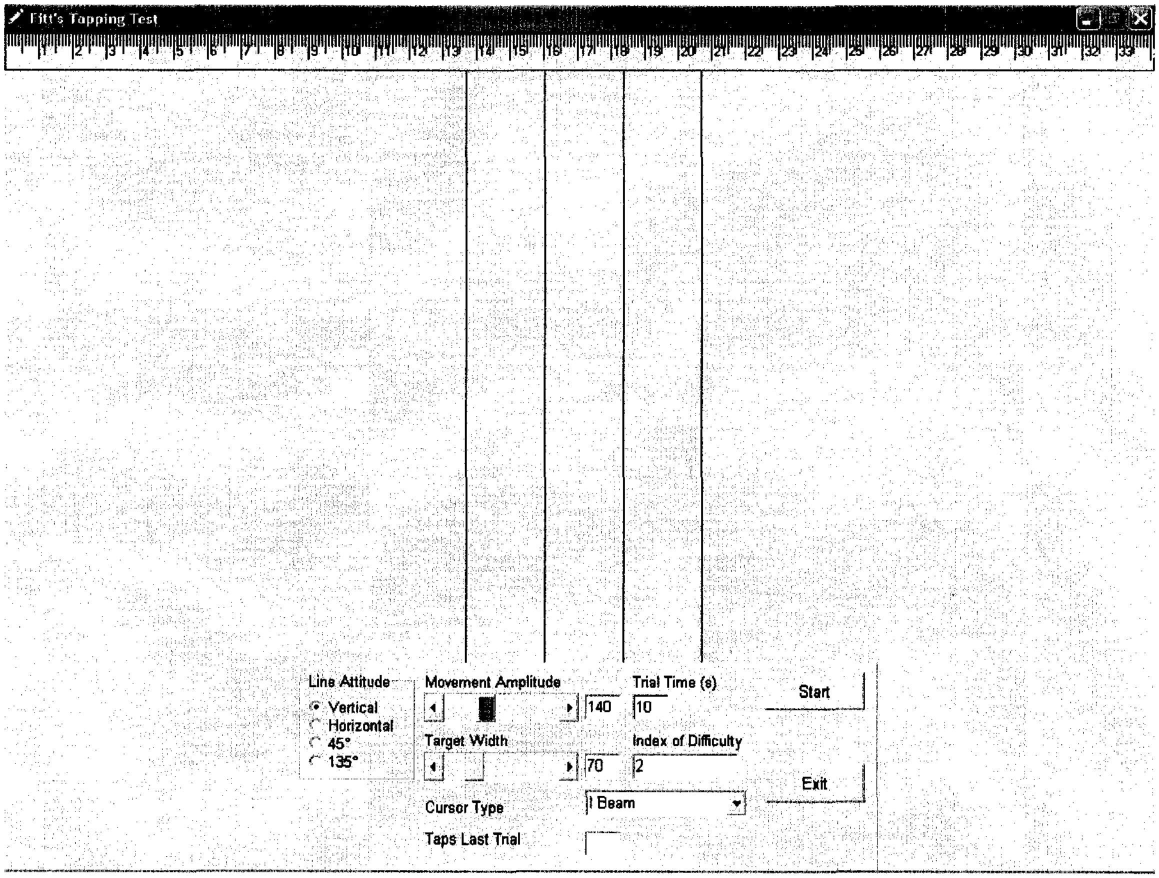
-2 -1 0 1 2

O'Conner Tweezer Dexterity Task

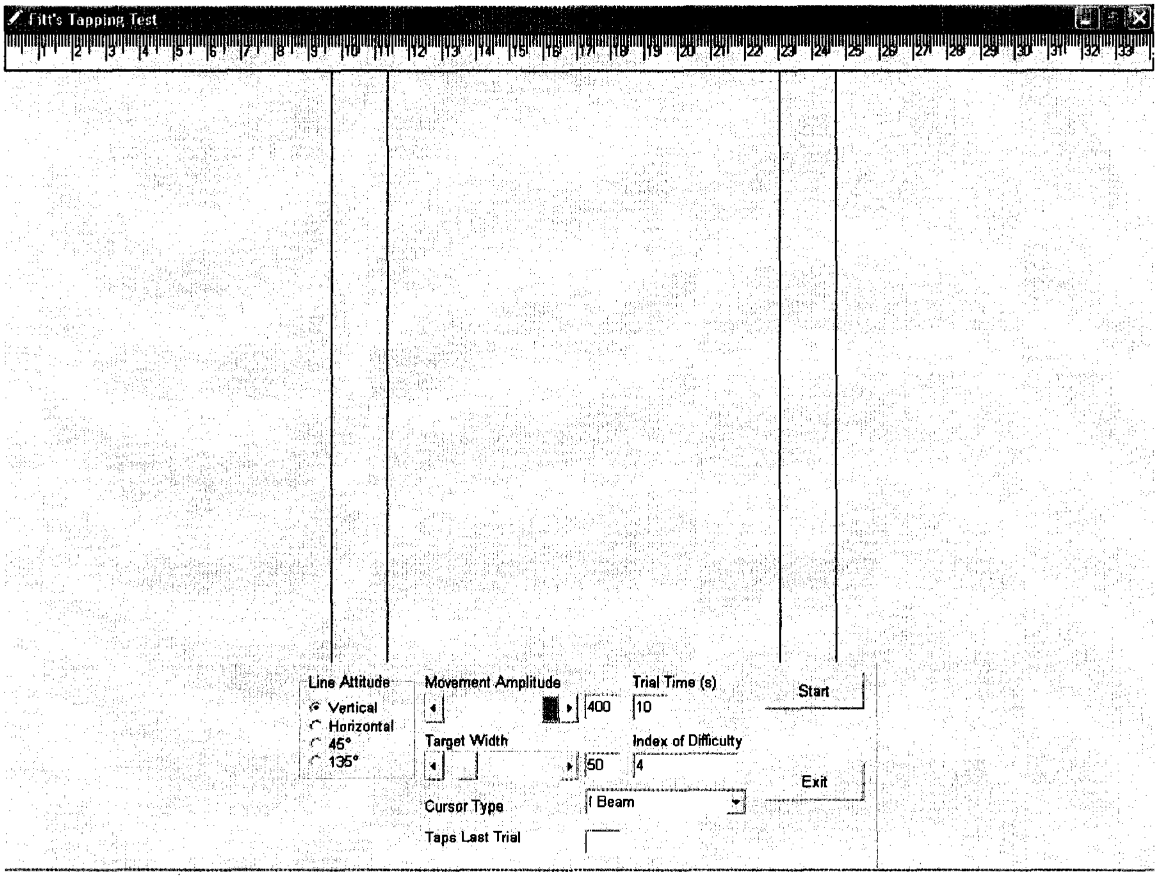
-2 -1 0 1 2

Appendix D

Fitts' Law – Index of Difficulty Two



Fitts' Law - Index of Difficulty Four



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